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PRESSURE LOSSES IN REGISTERS AND STACKHEADS IN FORCED WARM-AIR HEATING

A REPORT OF AN INVESTIGATION
CONDUCTED BY
THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
IN COOPERATION WITH
THE NATIONAL WARM-AIR HEATING AND
AIR CONDITIONING ASSOCIATION

BY
ALONZO P. KRATZ
AND
SEICHI KONZO

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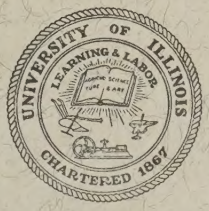

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PRESSURE LOSSES IN REGISTERS AND STACKHEADS

I. Introduction

1. *Preliminary Statement.*—Registers serve not only to conceal the opening out of which the air is delivered from a duct, but may also serve to regulate the flow, direct the air stream, and distribute the air delivered into a space or enclosure. The advent of the forced-air heating system for winter heating and summer cooling, with the accompanying use of high air velocities, has made it necessary that more attention be given to the direction of the air stream and the distribution of the air in a room. Nelson, Krans, and Tuthill* have shown that the velocity distribution in the air stream flowing from a stackhead and register combination is affected by the design and type of stackhead and register. The work of Nelson and Stewart,† as well as the investigations in progress at the University of Illinois,‡ have shown that the shape, size, and type of the inlet opening have a marked influence on the distribution of the air in a room and the resultant air velocity at any given point within the room. In connection with the use of high air velocities, the employment of more complicated forms of registers in order to obtain better direction of the air stream and more uniform distribution of the air in the room has resulted in higher resistances to air flow, and thus has made necessary more accurate information on the resistances of registers.

The air flowing through a register is subjected to complicated influences resulting in contraction, expansion, and deflection occurring within a distance of only a few inches of air travel. Hence, the pressure loss of the register is composed not only of friction losses caused by the rubbing action of the air on the surfaces of the duct and the register, but also of shock losses resulting from sudden contraction, expansion, and deflection of the air.

Quoting from Engineering Experiment Station Bulletin No. 300:

"Friction pressure losses may be studied by observing the decrease in static pressure occurring in a duct of uniform cross section. Since shock losses involve changes in velocity, they cannot be determined from observations of static pressure alone, but must be evaluated

*"The Performance of Stack Heads," by D. W. Nelson, D. H. Krans, and A. F. Tuthill, A.S.H.V.E. Trans. Vol. 46, 1940, pp. 205-222.
Also, "The Performance of Stack-Heads Equipped with Grilles," by D. W. Nelson, D. H. Lamb, and G. E. Smedberg, A.S.H.V.E. Journal Section, *Heating, Piping, and Air Conditioning*, Jan. 1942, pp. 61-68.

†"Air Distribution from Side Wall Outlets," by D. W. Nelson and D. J. Stewart, A.S.H.V.E. Trans. Vol. 44, 1938, pp. 77-92.

‡"Development of Instruments for the Study of Air Distribution in Rooms," by A. P. Kratz, A. E. Hershey, and R. B. Engdahl, A.S.H.V.E. Trans. Vol. 46, 1940, pp. 351-366.

from differences in total pressure, the latter consisting of the sum of the static pressure and the velocity pressure."*

In connection with the present investigation on registers it was also observed that the static pressure in the duct or stackhead immediately ahead of the register was not a significant index of the pressure loss, and that the total pressure ahead of the register constituted the only real index of performance.

2. *Objects and Scope of Investigation.*—The main objectives of this investigation may be stated as follows:

(1) To study the pressure gradients existing in the air stream on both sides of a register, and to derive a significant index for evaluating the pressure loss of the register.

(2) To determine pressure losses for air outlets of the following types:

(a) Rectangular sharp-edged orifices.
(b) Perforated grille type registers.
(c) Non-deflecting, bar type registers.
(d) Adjustable deflecting type registers.
(e) Fixed deflecting type registers.

(3) To determine the effect on the pressure loss of varying the size of borders on registers.

(4) To determine the pressure losses with registers attached either to the end of a straight duct or to a stackhead.

(5) To determine the effect on pressure loss of placing turning vanes in the stackhead.

(6) To determine the effect on the pressure loss of varying the relative sizes of registers and stackheads.

Commercial stock models of registers were used for most of these tests, and the measurements of pressure loss were made primarily with the object of establishing design factors by obtaining general relationships between pressure losses and various features of construction. Such design factors would be useful in the development of registers characterized by minimum pressure losses.

3. *Acknowledgments.*—This bulletin is the seventeenth to be published under the present cooperative agreement between the National Warm-Air Heating and Air Conditioning Association and the University of Illinois for an investigation of warm-air furnaces and furnace heating systems. The cooperating association has been represented by

*"Pressure Losses Resulting from Changes in Cross-Sectional Area in Air Ducts." Univ. of Ill. Eng. Exp. Sta. Bul. 300.

a Research Advisory Committee, the personnel of which changes somewhat from year to year. Since 1939, the following members of the Association have served on this Committee:

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Keith Davis (representing the American Gas Association), Mueller Furnace Company, Milwaukee, Wisconsin.

G. W. Denges, Williamson Heater Company, Cincinnati, Ohio.

R. A. Gulick, May-Fiebeger Company, Newark, Ohio.

F. L. Meyer, The Meyer Furnace Company, Peoria, Illinois.

C. W. Nessell, Minneapolis-Honeywell Regulator Company, Minneapolis, Minnesota.

R. M. Sherman (representing the Oil Burner Institute), Silent-Glow Oil Burner Corporation, Hartford, Connecticut.

This investigation has been carried on as a part of the work of the Engineering Experiment Station of the University of Illinois and as a project of the Department of Mechanical Engineering. The investigation was conducted under the general administrative direction of Dean M. L. Enger, Director of the Engineering Experiment Station, and of Professor O. A. Leutwiler, Head of the Department of Mechanical Engineering.

Acknowledgment is made to the following former graduate students, D. W. Thomson, Walter Kupchick, H. R. Stover, and L. B. Ritchey, for their services in conducting the tests and in the reduction of the test data.

Acknowledgment is also made to the various manufacturers who cooperated by furnishing registers and duct fittings used in the investigation.

II. Description of Testing Apparatus

4. *Test Plant.*—In the course of this investigation two general types of tests were run, one in which the registers were placed at the end of a straight 6-in. x 12-in. duct, and the other in which the registers were placed in a stackhead attached to a 3¼-in. x 12-in. stack. The testing apparatus, arranged as shown in Fig. 1, consisted of a fan, a circular pipe containing straightener tubes, a measuring station used to determine the weight of air flowing, a plenum chamber containing a baffle against which the air was discharged, and a removable plate to which was attached the test duct section and registers. The use of the two sets of straightener tubes, the plenum chamber, the baffle, and the re-entrant duct in the plenum chamber served to minimize

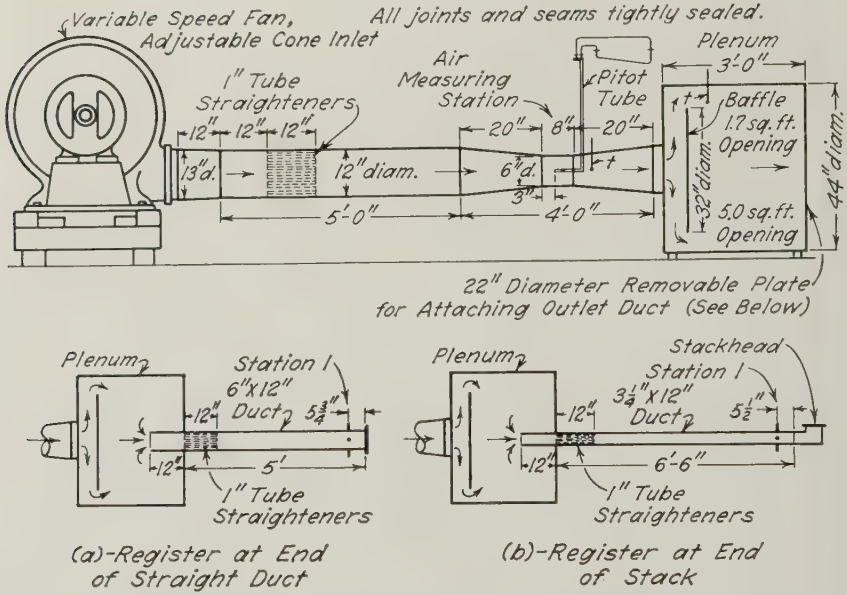

FIG. 1. DIAGRAM OF LABORATORY PLANT FOR MEASUREMENT OF PRESSURE LOSSES IN REGISTERS AND FITTINGS

both pulsations in air pressure and irregularities in the velocity contour of air flow.

The fan used was a plate-type volume blower having a nominal rating of 4700 cu. ft. of air delivered per min. against a 5-in. static pressure at a speed of 1960 rev. per min. The fan was direct connected to a variable-speed, 220-volt, d-c motor, the speed of which was controlled by means of a carbon-pile rheostat in the armature circuit. In addition, a cone was inserted in the inlet of the fan to provide for further regulation of the air flow. The position of this cone could be adjusted in order to vary the size of the inlet opening to the fan.

As shown in Fig. 1, the measuring station consisted of a venturi section containing a pitot tube placed in the central axis and used in connection with an inclined manometer. This measuring station was calibrated in place by making traverses with a pitot tube placed in successive positions in the horizontal and vertical diameters of the section. In this way, a single reading of the velocity pressure, made in the center of the section, could be used as a convenient guide in controlling the velocity of the air during a test, and as an index from which the weight of air flowing could be determined with an acceptable

degree of accuracy. The coefficient of all pitot tubes was assumed to be 1.00.

Traverses to determine both velocity and static pressures were made at various sections in the test duct. The velocity pressures were obtained by means of a standard pitot tube, and the static pressures were obtained from the static connections of the pitot tube. In addition, static pressure measurements were made at several stations by means of a piezometer ring attached at the center of each side of the duct. Four holes, each 0.04 in. in diameter were drilled in the duct, and the edges of the holes on the inside of the duct were made flush with the walls of the duct. Brass tubes ¼-in. in diameter were soldered in place over each of the four holes. These tubes were connected together by means of rubber tubing to form a piezometer ring, and the ring was then connected to an inclined manometer. All pressures were measured by means of inclined manometers of a type commonly used as draft gages, and reading directly to 0.01 in. of water.

Detailed descriptions of the orifices, registers, borders, and stackheads which were used are presented in connection with the discussions of test results.

III. Methods of Procedure

5. *Measurement of Weight of Air.*—For the purpose of calibrating the measuring station, the apparatus was arranged as shown in the upper part of Fig. 1. The calibration established the relation between the actual weight of air flowing, as determined by a 12-point velocity pressure traverse in the 6-in. measuring station, and the velocity pressure observed in the center of the section. Details of the calibration procedure, together with the calibration curve, are given in Appendix A. After the calibration had been completed, the pitot tube was clamped in the center position, and the weight of air flowing was thereafter obtained by using the observed center velocity pressure in connection with the calibration curve.

As a check on the weight of air, separate traverses were made with the pitot tube at Station 1 in the two arrangements shown in Fig. 1. The results obtained from these traverses were within one per cent of the weight determined from the readings made at the measuring section.

6. *Measurement of Total Pressure.*—As mentioned in Section 1, the resistance of registers must be determined from differences in total pressure. Preliminary studies discussed in Appendix B indicated

that, within the limits of accuracy required, the total pressure ahead of the register at Station 1 could be determined from static pressure measurements, made by means of a piezometer ring, and calculated values of the velocity pressure corresponding to the mean velocity, computed from the weight of air measured at the measuring station. On the other hand, these preliminary studies discussed in Appendix B indicated that it was not possible either to calculate or measure the total pressure on the downstream side at the register face with any degree of certainty, and that no real meaning could be assigned to this total pressure.

Since there seems to be no means of obtaining the total pressure on the downstream side of a register placed at the end of a duct, it might appear that the true register resistance could be obtained by placing it within a duct and measuring the total pressure in the duct ahead of and behind the register. This, however, is not feasible. Part of the resistance consists of loss incident to the expansion of the air after it passes the register. In either case it is not possible to separate this expansion loss from the friction and other shock losses, and it is included in the primary measurements. Since the expansion occurring in the duct is different from that occurring in the air leaving a register at the end of the duct, the pressure loss through a register within a duct is different from that through a register delivering air into a room, and the determination of such losses for the register within the duct would be without any practical value. Preliminary tests confirmed this conclusion, and, therefore, no attempt was made to employ such a method.

Since, in determining the total head on a fan, the velocity pressure at exit is always added to the pressure losses in the duct system, it is not necessary to evaluate the pressure loss in the register and the final velocity pressure separately. That is, the total effect of these two can be combined and stated as a total pressure characteristic of the register, and in this case this total pressure can be added to the remaining pressure losses in the duct system in order to obtain the total head on a fan. The total pressure as measured at Station 1 represents the total pressure characteristic of the different types of registers tested. For simplicity this total pressure has been designated as *pressure loss*, and was used in correlating the results of the tests. In case the final velocity pressure is small, as it is in forced-air heating practice, and the fan is selected on the basis of static pressure alone, neglecting the final velocity pressure, the use of the total pressure at the register as suggested gives results which are conservative.

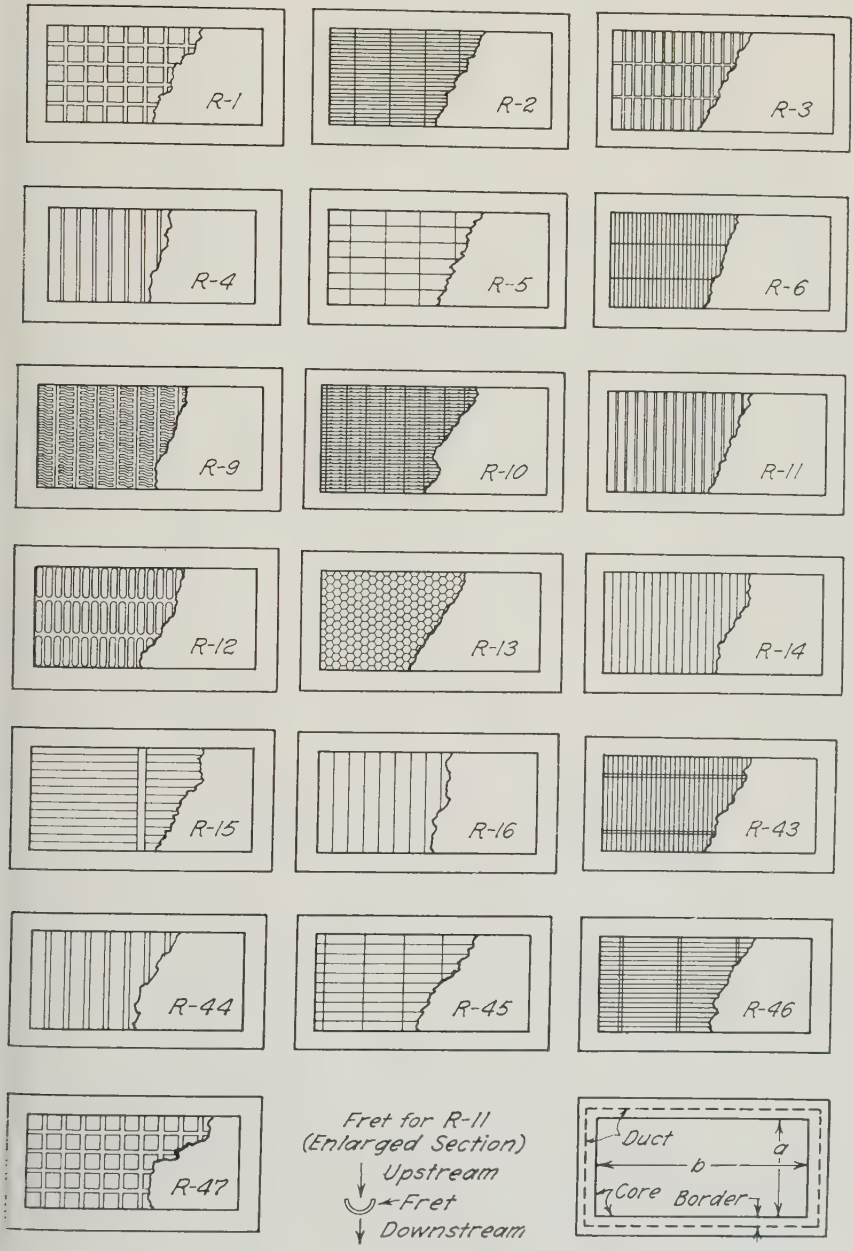

FIG. 2. DIAGRAMS OF NON-DEFLECTING TYPE REGISTERS

TABLE 1
DIMENSIONS OF NON-DEFLECTING TYPE REGISTERS

Register No.	Type	Test No.	Dimensions						Ratio of Width to Height of Core
			Core		Individual Openings		Frets		
			Height in.	Width in.	Height in.	Width in.	Width in.	Depth in.	
1	2	3	4	5	6	7	8	9	10
R1	Grille	1F	4.87	10.82	0.81	0.81	0.18	0.11	2.22
R2	Bar	2F	4.89	11.27	0.19	1.70	0.03	0.50	2.31
R3	Grille	3F	5.12	11.36	1.63	0.38	0.12	0.06	2.22
R4	Grille	4F	4.74	10.39	4.75	0.63	0.18	0.07	2.19
R5	Bar	5F	4.90	11.26	0.80	1.70	0.08	0.50	2.30
R6	Bar	6F	4.90	11.25	1.60	0.18	0.04	0.50	2.30
R9	Grille	9F	5.36	11.46	0.08	0.62	0.16	0.04	2.14
R10	Bar	10F	5.50	11.50	0.19	0.96	0.02	0.47	2.09
R11	Grille	22F	5.23	11.23	5.23	0.34	0.15	0.16	2.15
R12	Grille	12F	5.12	11.14	1.58	0.36	0.12	0.07	2.18
R13	Bar	13F	5.07	11.12	0.45	0.50	0.02	0.88	2.19
R14	Bar	14F	5.23	11.23	5.23	0.34	0.06	0.38	2.15
R15	Bar	15F	5.24	11.23	0.34	5.40	0.06	0.38	2.18
R16	Bar	16F	5.23	11.19	5.23	0.72	0.06	0.38	2.14
R43	Bar	25F	4.91	10.94	4.91	0.19	0.06	0.28	2.23
R44	Grille	26F	5.00	10.78	5.00	0.75	0.25	0.11	2.16
R45	Bar	27F	4.91	10.84	0.43	1.95	0.06	0.38	2.21
R46	Bar	28F	4.91	10.88	0.19	2.73	0.06	0.28	2.22
R47	Grille	29F	4.75	10.75	0.75	0.75	0.25	0.11	2.26

See Fig. 2 for description.

IV. PRESSURE LOSSES FOR NON-DEFLECTING TYPE REGISTERS

7. *Description of Registers Tested.*—Eight perforated grille registers and 18 bar registers of the non-deflecting type were included in the first series of tests, for which the test arrangement shown in Fig. 1a was used. Dampers, if furnished with the registers, were removed. In the non-deflecting type registers, the entire air stream is projected outwards perpendicular to the face of the register without being deflected vertically or horizontally. All of the registers shown in Fig. 2, together with seven which are shown in Fig. 10, were included in this series. For the latter group of registers, the results of only those tests in which the adjustable blades were set to provide no deflection of the air stream are presented in this section. Dimensional details of the registers tested are shown in Tables 1 and 6, and pressure losses are given in Tables 2 and 7.

8. *Results of Tests.*—For each register tested, the velocity of air in the approach duct was maintained constant, and the total pressure

TABLE 2
TOTAL PRESSURES FOR NON-DEFLECTING TYPE REGISTERS

Register No.*	Test No.	Area		Ratios		Total Pressure Ahead of Register, in. of water		Pressure Loss Ratio, $\frac{T.P.}{V.P.}$		
		Core Area sq. in.	Free Area sq. in.	Free Area to Core Area	Free Area to Duct Area	At 300 f.p.m.	At 1500 f.p.m.	At 300 f.p.m.†	At 1500 f.p.m.‡	Average
1	2	3	4	5	6	7	8	9	10	11
R1	1F	52.70	36.08	0.684	0.501	0.034	0.825	6.07	5.89	5.98
R2	2F	55.13	45.05	0.817	0.626	0.017	0.335	2.94	2.39	2.67
R3	3F	58.20	40.72	0.700	0.566	0.024	0.580	4.26	4.14	4.20
R4	4F	49.23	38.90	0.790	0.540	0.033	0.750	5.84	5.36	5.60
R5	5F	55.20	48.26	0.874	0.670	0.013	0.296	2.30	2.01	2.16
R6	6F	55.15	43.79	0.794	0.608	0.016	0.350	2.92	2.50	2.71
R9	9F	61.45	13.38	0.218	0.186	0.210	5.300	37.40	37.80	37.60
R10	10F	63.25	37.26¶	0.590	0.518	0.020	0.423	3.64	3.02	3.33
R11	22F	58.75	40.36	0.687	0.560	0.023	0.555	4.15	3.96	4.06
R12	12F	57.05	39.24	0.688	0.545	0.028	0.663	4.99	4.73	4.86
R13	13F	56.40	53.00	0.940	0.736	0.013	0.286	2.32	2.08	2.20
R14	14F	58.75	48.90	0.832	0.679	0.012	0.282	2.05	2.01	2.03
R15	15F	58.88	47.37	0.804	0.658	0.013	0.300	2.39	2.14	2.27
R16	16F	58.50	54.12	0.925	0.752	0.012	0.282	2.05	2.01	2.03
R43	25F	53.75	37.00	0.689	0.514	0.026	0.508	4.67	3.62	4.14
R44	26F	53.90	41.40	0.768	0.575	0.028	0.646	4.99	4.61	4.80
R45	27F	53.22	45.28	0.850	0.628	0.014	0.320	2.53	2.28	2.40
R46	28F	53.41	37.36	0.699	0.534	0.022	0.455	3.89	3.25	3.57
R47	29F	51.05	30.90	0.605	0.429	0.052	1.230	9.27	8.78	9.02

*See Fig. 2 for description, values in Column 11 shown in Fig. 3.
†Velocity pressure in duct at 300 f.p.m. is equal to 0.0056 in. water.
‡Velocity pressure in duct at 1500 f.p.m. is equal to 0.1401 in. water.
¶Based on free area at face.

ahead of the register was determined in the manner described in Appendix B. This procedure was repeated for at least seven other air velocities, and the resulting total pressures were plotted as ordinates on curves in which the air velocity was the abscissa. A typical curve of pressure losses for a register is shown as curve (1) in Fig. 26a, Appendix C. From these curves, the total pressures ahead of the registers were obtained for duct velocities of 300 ft. per min. and 1500 ft. per min. These total pressures are given in Table 2, columns 7 and 8. As explained in Appendix C, the pressure loss, as measured in inches of water, was also expressed as the ratio of the total pressure to the velocity pressure in the duct, or $\frac{T.P._{\cdot 1}}{V.P.}$. The values of this pressure loss ratio for duct velocities of 300 ft. per min. and 1500 ft. per min. are given in Table 2, columns 9 and 10, and in Table 7, columns 4 and 5. The average values of the pressure loss ratios are given in Table 2, column 11, and in Table 7, column 6.

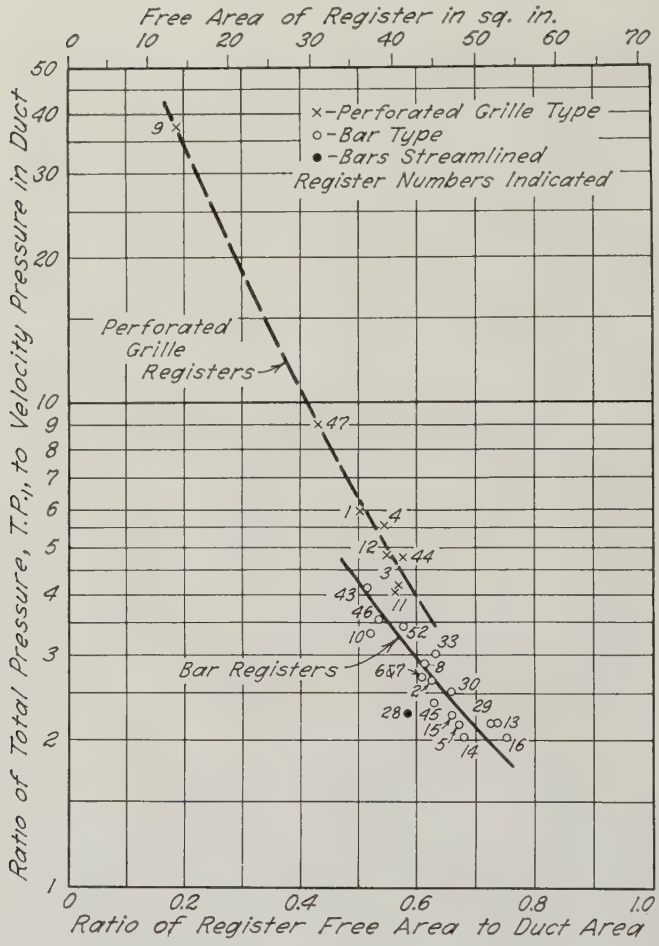

Fig. 3. Pressure Losses for Non-Deflecting Type Registers

Figure 3 shows a summary of results from all of the tests. The pressure loss ratio for each register was plotted against the ratio of free area of register to duct area. The ratio of free area to core area (see Fig. 2) is one commonly used in practice, but for registers of the same nominal size, the width of border, and therefore the core area, varied somewhat as shown in Table 2, column 3. However, since all registers were attached to the same duct, the duct area was the same in all cases, and the ratio of free area to duct area was considered the more significant figure. Furthermore, it was found that more con-

sistent results were obtained by plotting the pressure loss ratio against the ratio of free area to duct area than by plotting it against the ratio of free area to core area. For convenience, a scale of actual free areas is shown at the top of Fig. 3, but this scale has no general significance, since the free areas apply only to the particular sizes of registers tested.

It may be observed from Fig. 3 that with both bar and perforated grille types of registers the pressure loss ratios decreased as the free area ratios were increased. Furthermore, for given free area ratios, the pressure loss ratios, as shown by the curves, were substantially less for the bar type registers than they were for the perforated grille type. In the case of the bar type registers, the range of pressure loss ratios was from 2 to 4, with those for the majority of the cases falling in the range between 2 and 3. On the other hand, the overall range of the pressure loss ratios for the perforated grille registers was from about 4 to 37.5, with those for the majority of the cases falling in the range between 4 and 6. A further discussion of pressure losses as related to combinations of borders and frets is presented in Chapter V.

It is not unusual for registers in forced-air systems to be operated with an air velocity of 600 ft. per min. in the approach duct, corresponding to a velocity pressure of 0.022 inches of water. Under these conditions, therefore, the actual pressure losses through the registers would range from 0.044 to 0.066 inches of water for the majority of bar type registers, and from 0.088 to 0.132 inches of water for the perforated grille type. Small forced-air systems are commonly designed for available pressures at the entrance of the warm air duct ranging from 0.06 to 0.10 inches of water. Hence it is evident that the pressure loss through a register may be comparable with the total amount of pressure available for forcing the air through the warm-air duct system, and the necessity for taking into consideration the pressure losses of the individual registers used cannot be too strongly emphasized.

The fretwork in register R28 was composed of streamlined, or teardrop shaped, bars. Each bar had a rounded nose on the upstream side and tapered to a thin edge on the downstream side. As may be observed from Fig. 3, at the same free area ratio the pressure loss ratio for this register was considerably lower than the corresponding value read from the curve representing the pressure loss ratios for the other bar type registers. The shape of the bar undoubtedly contributed to the reduced pressure loss. Register R11 was composed of frets stamped in the shape of a semi-circular trough, as shown in the inset

(a)

(b)

FIG. 4. STREAM LINES AROUND OBSTRUCTIONS

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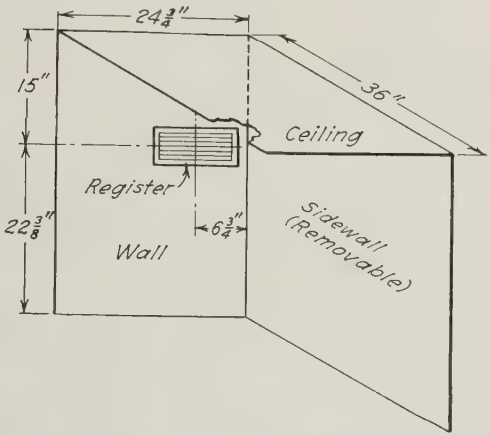


FIG. 5. ARRANGEMENT USED IN DETERMINING EFFECT OF WALLS AND CEILING

in the lower part of Fig. 2. The open part of the trough faced upstream, and the rounded portion was on the downstream side of the register, thus providing some amount of streamlining. As shown in Fig. 3, the point representing this register fell below the average curve for perforated grille registers.

In connection with the difference in performance obtained with the bar and perforated grille type registers, respectively, a photographic study made by Prandtl and Tietjens* of the flow of fluids around obstructions is of direct interest, and for the purpose of comparison two diagrams shown in the original volume are reproduced in Fig. 4. The turbulence in the fluid stream on the downstream side of a thin wide obstruction (a), corresponding to the fret of a perforated grille type register, was quite marked, whereas, in the case of a long narrow obstruction (b), corresponding to a bar, the streamlines were preserved and little turbulence was noted. It is probable that similar phenomena accompanied the flow of air around the frets in the registers, and that the noticeable differences in pressure losses between the bar and the perforated grille fretworks could be accounted for by differences in the amount of energy dissipated in the form of turbulence in the two cases.

9. *Effect of Dampers.*—Three of the registers (R2, R6, and R12) were tested with dampers in place and in an open position. With the

*"Applied Hydro- and Aeromechanics," by L. Prandtl and O. G. Tietjens, McGraw-Hill Book Co., 1934, pp. 305-306.

Table 3
Arrangement of Walls and Ceiling Used in Conjunction With Registers

Register No.	Type	Combination
R1	Non-deflecting	Wall and Ceiling
R7	Non-deflecting	Wall and Ceiling
R15	Non-deflecting	Wall and Ceiling
R11	Non-deflecting	Wall and Ceiling
R11	Non-deflecting	Wall, Ceiling, and Sidewall
R19*	Deflecting	Wall and Ceiling
R19*	Deflecting Against Sidewall	Wall, Ceiling, and Sidewall

*Description in Fig. 14 and Table 8.

dampers opened so that they were parallel to the axis of the duct, thus forming an air pocket between the damper and the wall of the duct, the pressure losses observed with given air velocities were from 5 to 25 per cent greater than the corresponding losses obtained with the dampers removed. The larger percentages were obtained with high rates of air flow. On the other hand, when the dampers were swung wide open so that they touched the duct, thus eliminating the air pocket, the observed pressure losses were less than those obtained for the same registers with the dampers removed.

10. *Effect of Adjacent Walls and Ceiling.*—In order to simulate the effect of nearby walls and ceilings, the arrangement shown in Fig. 5 used in connection with the testing apparatus shown in Fig. 1a was employed, and a few tests were made to determine whether or not such adjacent surfaces had any effect on the pressure loss, and whether or not the effect, if it existed, was sufficient to make necessary any modification of the testing procedure. The results of these tests are shown in Table 3. In no case was any difference in total pressures observed, whether the adjacent walls and ceiling were used or not. Such adjacent surfaces do have a marked influence on the manner in which the air currents move within an enclosed space. Apparently, however, once the air is discharged from the duct and register into a relatively large space, any external influences that might affect the path of the air currents are not reflected in the pressure inside of the duct. Hence, all of the registers and combinations of registers and stackheads were tested with the air delivered freely into an unobstructed space.

TABLE 4
DIMENSIONS AND TOTAL PRESSURES FOR BORDERS TESTED

Border No.	Test No.	Core			Ratio of Free Area to Duct Area	Total Pressure Ahead of Border, in. of water		Pressure Loss Ratio, $\frac{T.P.}{V.P.}$		
		Size in.	Ratio of Width to Height	Free Area sq. in.		At 300 f.p.m.	At 1500 f.p.m.	At 300 f.p.m.	At 1500 f.p.m.	Average
1	2	3	4	5	6	7	8	9	10	11
O2	1H	11.28 x 5.27	2.14	59.48	0.826	0.012	0.275	2.14	1.96	2.05
O3	2H	10.76 x 5.06	2.13	54.48	0.756	0.015	0.352	2.71	2.51	2.61
O4	3H	10.19 x 4.76	2.14	48.52	0.674	0.021	0.483	3.74	3.45	3.60
O5	4H	8.89 x 4.15	2.14	36.90	0.512	0.043	0.985	7.74	7.03	7.38
O6	5H	7.48 x 3.47	2.15	25.96	0.360	0.099	2.260	17.56	16.13	16.85
O7	8H	5.69 x 2.63	2.16	14.96	0.208	0.331	7.250	59.00	51.75	55.38
B3	31L	10.54 x 4.56	2.31	48.06	0.668	0.023	0.510	4.10	3.64	3.87

V. PRESSURE LOSSES AS AFFECTED BY BORDERS AND FRETWORK

11. *Pressure Losses for Borders and Fretwork Used Separately.*—It may be observed from columns 4 and 5 of Table 1 that the core openings for the registers were in all cases smaller than the duct to which the register was attached. The border has been defined as the strip of metal between the outer edges of the core and the walls of the duct, and is shown in the lower inset in Fig. 2. The dimensions given in Table 2, column 3 show that the core area, and hence the size of the borders tested, varied to some extent. There was no assurance that a given reduction in duct area resulting from the use of a border had the same effect on the pressure loss as the same reduction in duct area brought about by the fretwork alone. Neither was there any assurance that the effect of the pressure loss with the border alone would be the same as that when the same border was used in connection with frets. Hence, tests were made to determine the effect of the size of the border on the pressure loss.

In one series of tests the borders described in Table 4 were attached to the end of the 6-in. x 12-in. duct, as shown in Fig. 1a, and the total pressures ahead of the borders, which were in effect thin plate orifices, were determined as discussed in Appendix B. The aspect ratios of the cores, given in Table 4, column 4, were approximately of the same order of magnitude as those for the registers shown in Table 1, column 10. The pressure loss ratios were plotted against the ratios of

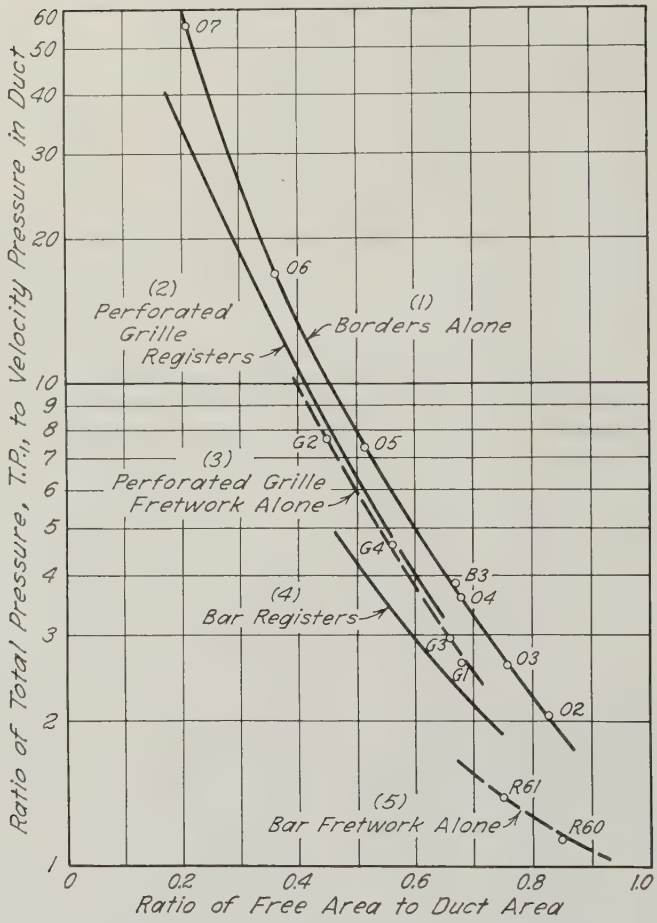


FIG. 6. PRESSURE LOSSES FOR BORDERS AND FRETS

free area to duct area, as shown in Fig. 6, curve 1. The same figure also shows the pressure loss ratios for the perforated grille registers (curve 2) and bar registers (curve 4), which were transposed from Fig. 3. For a given free area the pressure loss for a border used alone was greater than that for either a perforated grille or bar register, indicating that the loss due to turbulence from a single large orifice was greater than that accompanying a number of small openings in close proximity in the same plane.

Curves 3 and 5 in Fig. 6 show the pressure losses occurring when no borders were used, and the entire face of the 6-in. x 12-in. duct

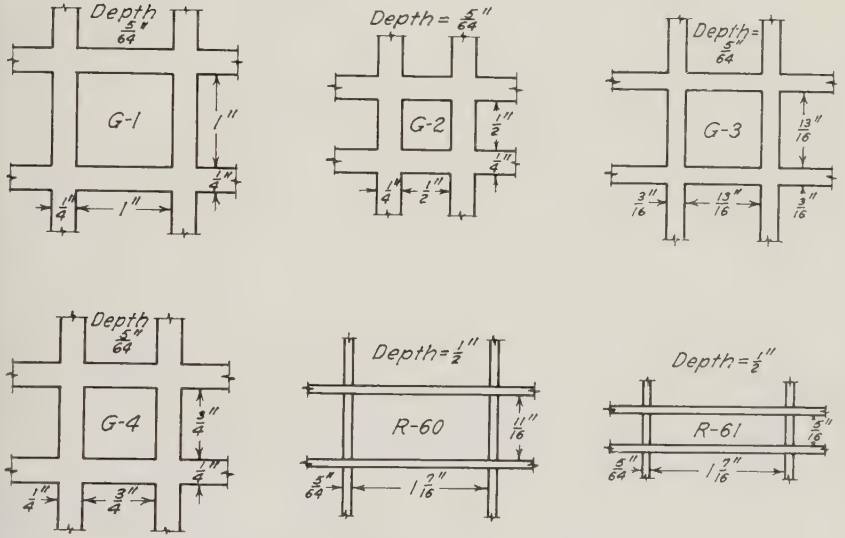


FIG. 7. DETAILS OF PERFORATED GRILLE AND BAR FRETWORKS

was covered by perforated grille or bar fretworks. The details of the grilles and bars used are given in Fig. 7 and Table 5A. The pressure losses for both the perforated grille and the bar fretworks used alone were less than those for the same fretworks used in combination with a border, and all of them were less than that for the border alone. Furthermore, the pressure loss for the bar fretwork was less than that for the perforated grille fretwork. Apparently, the turbulence caused by the comparatively long frets in the bar fretwork was not as great as that caused by the very short frets in the perforated grille fretwork. From the differences between curves 2 and 3 and between curves 4 and 5, in Fig. 6, it may be concluded that in a complete register the effect of the border in increasing the pressure loss was relatively greater for the bar registers than it was for the perforated grille registers. From these results it is evident that the pressure loss for a register is greatly influenced by the size of the border.

12. *Pressure Losses for Combinations of Borders and Frets.*—Additional tests were conducted in which the frets shown in Fig. 7 were attached to the end of the duct shown in the test arrangement in Fig. 1a, and the size of the border was progressively increased by masking portions of the fretwork near the walls of the duct. The data for this series of tests are presented in Table 5b, and the results ob-

Table 5

Dimensions and Total Pressures for Combinations of Borders and Frets

A. Tests With Frets Alone

Fret No.	Type of Fret	Test No.	Number of Rows of Individual Openings		Free Area sq. in.	Ratio Free Area to Duct Area	Total Pressure Ahead of Frets, in. of water		Pressure Loss Ratio, $\frac{T.P.}{V.P.}$		
			Horiz.	Vert.			At 300 f.p.m.	At 1500 f.p.m.	At 300 f.p.m.	At 1500 f.p.m.	Average
1	2	3	4	5	6	7	8	9	10	11	12
G1	Grille	4L	10	5	48.75	0.678	0.015	0.358	2.70	2.56	2.63
G2	Grille	3L	16	8	32.00	0.445	0.017	1.000	8.21	7.14	7.68
G3	Grille	1L	12	6	47.48	0.660	0.046	0.410	3.00	2.93	2.96
G4	Grille	2L	12	6	40.50	0.563	0.028	0.622	5.00	4.44	4.72
R60	Bar	6L	8	8	61.14	0.849	0.007	0.151	1.20	1.08	1.14
R61	Bar	5L	8	16	54.03	0.750	0.008	0.181	1.48	1.29	1.39

B. Tests With Combinations of Borders and Frets

Fret or Register No.	Type of Fret	Test No.	Number of Rows of Individual Openings		Free Area sq. in.	Ratio Free Area to Duct Area	Total Pressure at 300 f.p.m. Duct Velocity	
			Horizontal	Vertical			in. of water	Ratio $\frac{T.P.}{V.P.}$
1	2	3	4	5	6	7	8	9
G2	Grille	3L	16	8	32.00	0.445	0.017	8.2
G2	Grille	12L	15	7	26.25	0.364	0.081	14.5
G2	Grille	13L	13	7	22.70	0.315	0.116	20.7
G2	Grille	14L	13	5	16.20	0.225	0.229	40.9
G4	Grille	2L	12	6	40.50	0.563	0.028	5.0
G4	Grille	7L	11	5	30.90	0.429	0.065	11.6
G4	Grille	8L	9	5	25.30	0.352	0.097	17.3
G4	Grille	9L	9	3	15.20	0.211	0.290	51.8
G4	Grille	10L	7	3	11.80	0.164	0.492	87.8
R60	Bar	6L	8	8	61.14	0.849	0.007	1.2
R60	Bar	15L	7	6	41.45	0.575	0.028	5.0
R60	Bar	16L	7	4	27.60	0.384	0.076	13.6
R60	Bar	17L	5	4	19.71	0.274	0.160	28.6
R61	Bar	5L	8	16	54.03	0.750	0.008	1.5
R61	Bar	18L	7	12	37.70	0.524	0.025	4.5
R61	Bar	19L	7	10	31.40	0.436	0.039	7.0
R61	Bar	20L	5	10	22.45	0.312	0.082	14.6
R61	Bar	21L	5	8	17.96	0.249	0.141	25.2
R3	Grille	3F	23	3	40.72	0.566	0.024	4.3
R3	Grille	29L	21	3	37.06	0.515	0.029	5.2
R3	Grille	30L	19	3	33.41	0.464	0.037	6.6
R5	Bar	5F	7	6	48.26	0.670	0.013	2.3
R5	Bar	27L	7	4	34.20	0.475	0.042	7.5
R5	Bar	28L	5	4	26.40	0.367	0.074	13.2
R9	Grille	9F	11.5	22	13.38	0.186	0.210	37.4
R9	Grille	25L	10	18	9.65	0.134	0.429	76.6
R9	Grille	26L	9	14	6.75	0.094	0.903	161.3
R13	Bar	13F	27	10.5	53.00	0.736	0.013	2.3
R13	Bar	22L	23	7.5	32.86	0.457	0.043	7.7
R13	Bar	23L	21	5.5	21.94	0.305	0.098	17.5
R13	Bar	24L	17	4.0	13.37	0.186	0.275	49.1

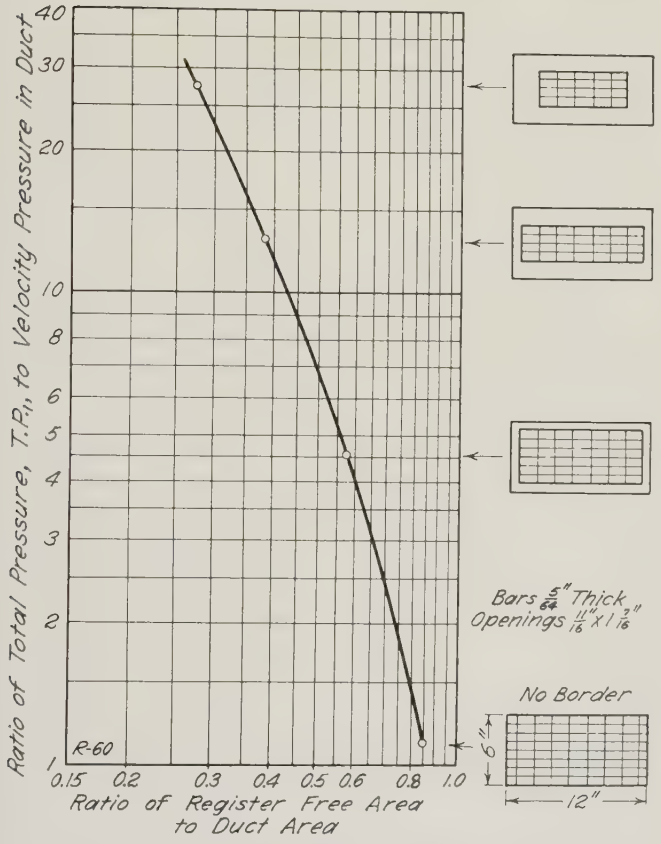


FIG. 8. PRESSURE LOSSES FOR DIFFERENT SIZED BORDERS USED WITH BAR TYPE REGISTER

tained from a typical series of tests are shown in Fig. 8. Very slight increases in the size of the border resulted in exceedingly large increases in the total pressure. Similar results for other types of frets and registers tested are shown in Table 5B and Fig. 9. For most of the registers tested, the curves representing each type of fret were approximately parallel with the curve for the border only. Hence, with any of these types of registers, in case the same fret is used and the size of the border is varied, the approximate pressure loss may be estimated readily if the pressure loss for the fretwork alone is known. For example, the lowest point on the curve for perforated grille G2 represents the pressure loss for this fretwork alone, or used without a border. On the assumption that this point were known, it is evident

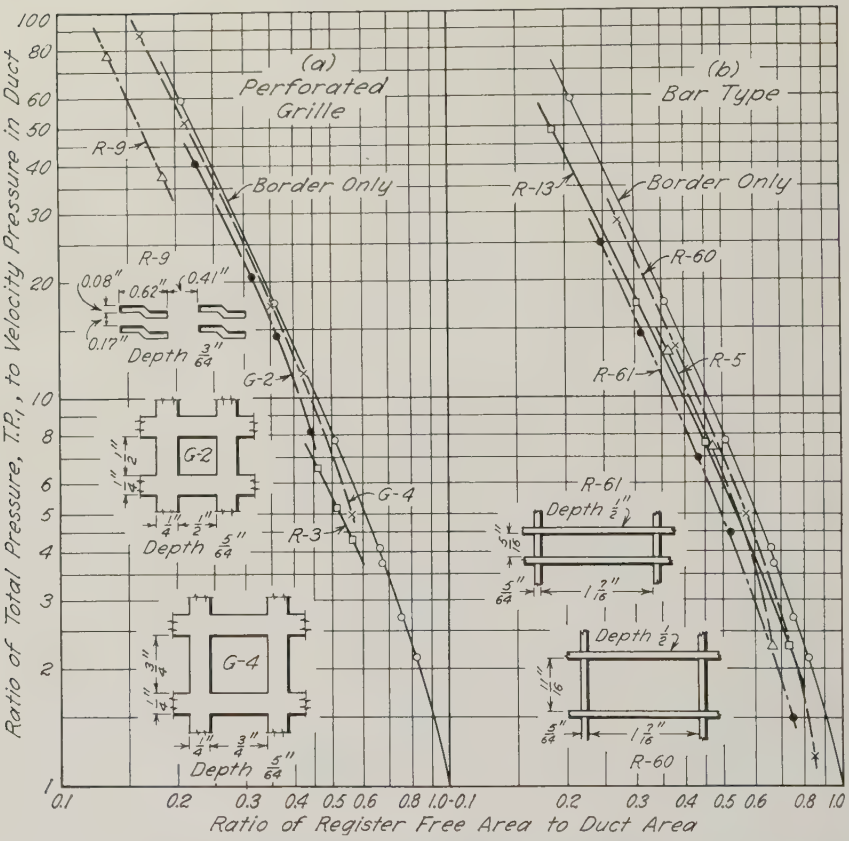


Fig. 9. Pressure Losses for Different Sized Borders Used With Perforated Grille and Bar Type Registers

that the curve representing the pressure loss through this type of fretwork used in connection with different size borders could be approximately reproduced by drawing a curve through this point parallel to the curve for borders only, without making a number of tests with different size borders. That is, one test with the fretwork alone should be sufficient. The pressure losses for the perforated grille and bar type fretworks used alone are shown in Fig. 6, curves 3 and 5.

In general, if minimum pressure losses are desired for any given size of register, the core area should be made as large as possible. In addition, the use of bar type frets in preference to perforated grilles is advisable.

VI. Pressure Losses for Deflecting Type Registers

13. *Description of Adjustable Deflecting Type Registers.*—A deflecting type register has been defined as that in which all or part of the air stream is projected outwards at an oblique angle to the register face. The deflecting type registers used in this series of tests were tested in the arrangement shown in Fig. 1a, and were equipped with either horizontal bars that could be adjusted to deflect the air downwards, vertical bars that could be adjusted to deflect air sideways, or both. Line diagrams of the eight registers tested are shown in Fig. 10, and dimensional details are given in Table 6. With the exception of register R18, the bars in all of the registers could be adjusted to give zero deflection of the air, and the pressure losses for zero deflection are shown in Table 7, columns 4 to 7. These data for the seven registers are also shown in Fig. 3. In the case of register R18, only the back set, or horizontal bars, were adjustable, and the front set, or vertical bars, were fixed in position and deflected the air a small amount to both sides. Hence the data for register R18, pre-

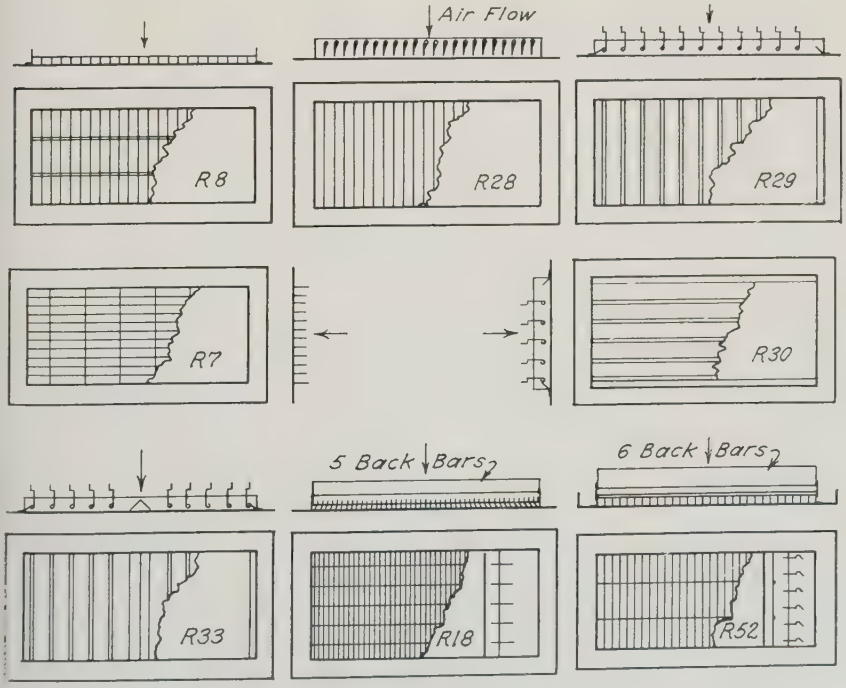


Fig. 10. Diagrams of Adjustable Deflecting Type Registers

TABLE 6
DIMENSIONS OF ADJUSTABLE, DEFLECTING TYPE REGISTERS

Register No.*	Dimensions						Ratio of Width to Height of Core	Areas		Ratios†	
	Core		Individual Openings†		Frets			Core Area sq in.	Free Area† sq. in.	Free Area to Core Area	Free Area to Duct Area
	Height in.	Width in.	Height in.	Width in.	Width in.	Depth in.					
1	2	3	4	5	6	7	8	9	10	11	12
R8	4.90	11.26	1.60	0.38	0.08	0.50	2.30	55.20	44.04	0.798	0.612
R28	5.53	11.54	5.53	0.45	{Front} 0.04	0.75	2.09	63.90	41.91‡	0.656	0.582
R29	5.54	10.85	5.54	0.82	{Front} 0.18	1.32	1.96	60.12	52.03	0.866	0.723
R7	4.89	11.26	0.35	1.65	0.08	0.50	2.30	55.09	43.79	0.795	0.608
R30	4.82	11.55	0.82	11.55	{Front} 0.18	1.32	2.40	55.70	47.36	0.850	0.658
R33	5.53	11.20	5.53	0.83	{Front} 0.18	1.32	2.03	61.94	45.50	0.735	0.632
R18	5.48	11.52	5.48	0.22	{Front} 0.02	0.50	2.10	63.20	41.96	0.664	0.583
R52	4.90	11.22	1.58	0.35	0.08	0.50	2.29	55.00	41.43¶	0.754	0.576

*See Fig. 10 for description.
†Based on zero deflection. That is with adjustable blades set perpendicular to face of register.
‡Streamlined bars. Free area based on narrowest cross section through register.
¶Based on free area of face.

sented in Table 7, columns 4 to 7, apply to the case in which only the back set of bars were adjusted to give zero deflection of the air. In the case of register R52, both the front and back set of bars could be adjusted independently, so that an unlimited number of combinations of deflections downwards and sideways were obtainable.

14. *Results of Tests on Adjustable Deflecting Type Registers.*—For each of the registers tested the bars were carefully adjusted to a predetermined angle of deflection, and the pressure losses over a wide range of velocities were measured. The angle of deflection was then changed and the procedure was repeated. A typical set of test data for an adjustable, deflecting type register are shown in Fig. 11. It may be observed that the pressure losses increased rapidly as the angle of deflection was increased. The total pressures ahead of the register for various angles of deflection ranging from 0 deg. to 75 deg., are presented in Table 7, columns 7 to 13. The pressure losses, expressed in inches of water, were in all cases for an air velocity of 900 ft. per min. in the duct, and hence are directly comparable. For each register tested, the pressure loss for 0 deg. deflection was regarded as unity, and the pressure losses for the different angles of deflection were expressed as ratios of the observed pressure losses to this basic

Table 7
Total Pressures for Adjustable, Deflecting Type Registers

Register No.*	Test No.	Deflection†	Pressure Loss Ratio, $\frac{T.P.}{V.P.}$ for 0 degree Deflection			Total Pressure¶ Ahead of Register, in Inches of Water for Angles of Deflection of						
			At 300 c.f.m.	At 1500 c.f.m.	Average	0°	15°	22°	30°	45°	60°	75°
1	2	3	4	5	6‡	7	8	9	10	11	12	13
R8	1K to 5K	To right	3.06	2.73	2.90	0.140	.....	0.188	0.226	0.408	1.070	.....
R28	28K, 36K, 37K	To left	2.49	2.08	2.28	0.109	.....	.....	0.185	0.336	.....	.....
R29	11K to 16K	To right	2.32	2.07	2.19	0.107	.....	0.142	0.165	0.316	0.874	4.44§
R7	17K to 20K	Down	2.92	2.50	2.71	0.132	.....	0.189	0.244	0.517	.....	.....
R30	21K to 26K	Down	2.67	2.40	2.53	0.124	.....	0.156	0.186	0.428	1.420§	13.10§
R33	32K to 35K	Right and left	3.21	2.86	3.03	0.147	0.157	.....	0.213	0.380	.....	.....
R18	3D to 6D	Down	2.38	1.86	2.12	0.101	0.109	.....	0.181	0.367	.....	.....
R52	38K, 41K, 44K	Back—none Front—right and left	3.74	3.14	3.44	0.166	0.195	.....	0.283	.....	.....	.....
R52	39K, 42K, 45K	Back—15° down Front—right and left	....	....	....	0.190	0.213	.....	0.299	.....	.....	.....
R52	40K, 43K, 46K	Back—30° down Front—right and left	....	....	....	0.270	0.283	.....	0.360	.....	.....	.....
						Angle of Deflection						
						−6°	0°	9°	24°	39°		
R28	27K to 31K	Right and left	2.49	2.08	2.28	0.119	0.109	0.112	0.163	0.270	.....	.....

*See Fig. 10 for description.
†Facing outwards from inside of duct.
‡All data in this column, except for R18, included in Fig. 3.
¶Determined for duct velocity of 900 f.p.m.
§Curve extrapolated to 900 f.p.m.

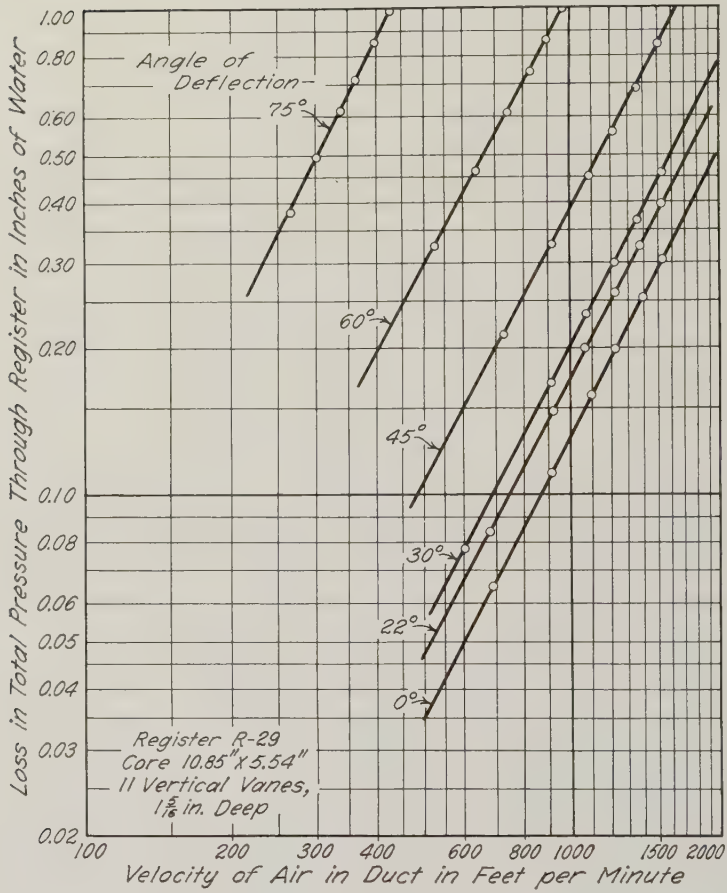


Fig. 11. Pressure Losses for Typical Deflecting Type Register

pressure loss. As shown in Fig. 12, these ratios, representing the increase in pressure loss over that for zero deflection, were plotted as ordinates against the angles of deflection used in the tests, and a curve was drawn through the average values of the ratios obtained for each angle of deflection. The points for the individual registers deviated somewhat from the curve, but the general trend is clearly defined. For angles of deflection smaller than about 30 deg., the increase in pressure loss above the base value was relatively small, but for angles of deflection greater than 30 deg. the rate of increase was much more rapid. For example, the ratios expressing the increase in pressure loss were approximately 1.1, 1.7, 3.3, and 9.1 for angles of deflection of 15,

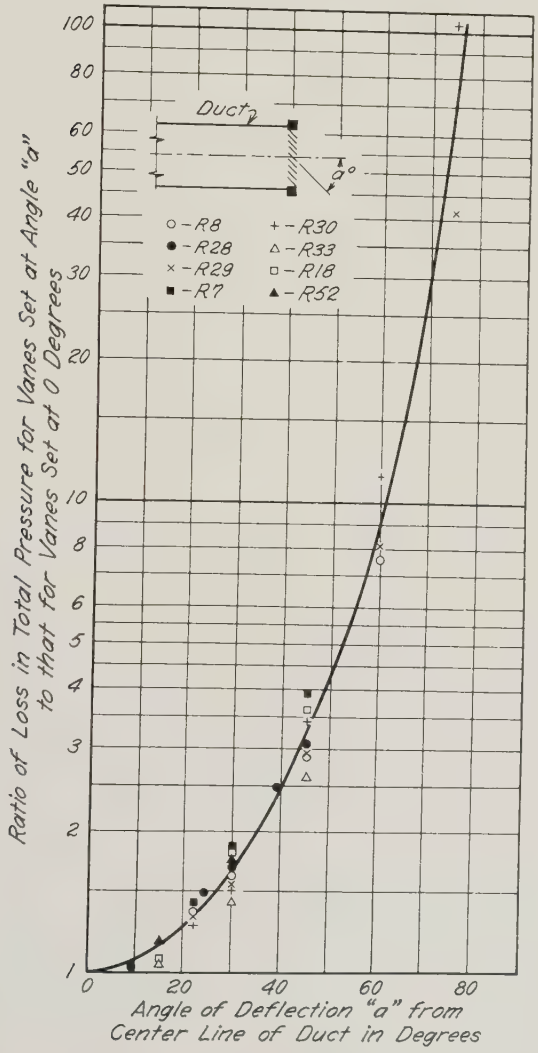


FIG. 12. INCREASE IN PRESSURE LOSS WITH DIFFERENT ANGLES OF DEFLECTION

20, 45, and 60 deg., respectively. A comparison of the separate points on the curve indicates that there was some tendency for the increase in pressure loss with downward deflection to be somewhat greater than that with sidewise deflection. However, the data were not sufficiently consistent to permit drawing any general conclusion.

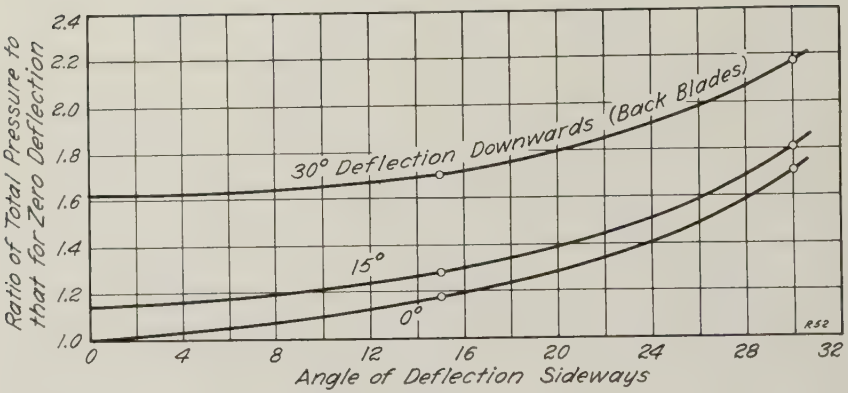


Fig. 13. Increase in Pressure Losses for Two-Way Deflecting Type Register

The results of tests with register R52, adjusted to give both sidewise and downward deflection, are shown in Fig. 13. It is evident that with zero deg. downward deflection the pressure loss increased as the angle of sidewise deflection was increased, and that with each value of the angle of sidewise deflection the pressure loss was further increased when downward deflection was superimposed. This latter increase was relatively greater for small angles of sidewise deflection than it was for large angles. It is also interesting to note that the pressure loss ratio for 30 deg. sidewise deflection alone, as read from the lowest curve, was practically the same as that for 30 deg. downward deflection, alone, as read from the upper curve.

15. *Results of Tests on Fixed Deflecting Type Registers.*—Details of the fixed deflecting type registers are shown in Fig. 14 and dimensions are given in Table 8A. With the exception of registers R19 and R27, the frets in these registers consisted of turning vanes having one-half of each vane parallel to the axis of the duct and the remaining half at an angle of 22 deg. The pressure loss ratios for these registers are given in Table 8B.

It was shown in Section 14 that the pressure loss for any given angle of deflection could be obtained from the pressure loss existing when the base angle of deflection was zero, or, in other words, when the bars were parallel to the axis of the duct. If, in the case of the fixed deflecting type of register, the bars are assumed to be turned parallel to the axis of the duct, that is, in the basic zero angle position, the basic free area becomes the same as the frontal free area measured

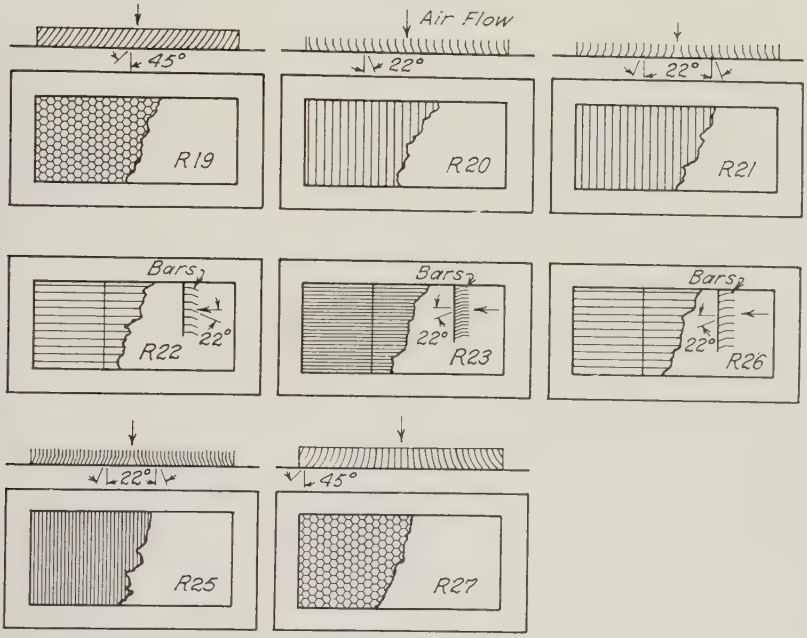


Fig. 14. Diagrams of Fixed Deflecting Type Registers

in the plane of the face of the register. The basic pressure loss ratio for a register having this free area, expressed as the ratio of free area to duct area, can then be read from the proper curve in Fig. 6. The ratio of the observed pressure loss ratio to the basic pressure loss ratio read from the curve can then be compared with the value read from the curve in Fig. 12 obtained for the adjustable deflecting type registers. For each of the fixed deflecting type registers, the frontal free area is shown in Table 9, column 3, and the corresponding basic pressure loss ratio for zero deflection, as determined from Fig. 6, is shown in Table 9, column 4. The ratio of the observed pressure loss ratio for the fixed deflection case to the basic value for the non-deflecting arrangement is shown in column 5. The average ratio obtained from column 5 for the seven registers having a 22-deg. angle of deflection was 1.324, whereas the corresponding ratio read from the curve in Fig. 12 was 1.32. The two values are in close agreement, and represent an increase of 32 per cent in the pressure loss. Hence, in the design of a fixed, deflecting type register, the approximate pressure loss may be estimated by first determining the pressure loss ratio from Fig. 6 for the appropriate frontal free area, and then multiplying the

TABLE 8

DIMENSIONS AND TOTAL PRESSURES FOR FIXED, DEFLECTING TYPE REGISTERS

A. Dimensional Details

Register No.	Test No.	Register Type	Dimensions						Ratio of Width to Height of Core
			Core		Individual Openings at Face		Frets		
			Height, a in.	Width, b in.	Width in.	Height in.	Width in.	Depth in.	
1	2	3	4	5	6	7	8	9	10
R19	1J	Bar	5.06	11.13	0.50	0.45	0.02	0.906	2.20
R20	2J	Bar	5.22	11.23	0.40	5.22	0.03	0.625	2.15
R21	3J	Bar	5.22	11.23	0.40	5.22	0.03	0.687	2.15
R22	8J	Bar	5.22	11.23	3.72	0.40	0.03	0.625	2.15
R23	4J	Bar	5.22	11.23	3.72	0.18	0.025	0.594	2.15
R26	6J	Bar	5.22	11.23	3.72	0.40	0.03	0.687	2.15
R25	5J	Bar	5.22	11.23	0.18	5.22	0.025	0.656	2.15
R27	7J	Bar	5.09	11.10	Variable	Variable	0.02	0.906	2.18

B. Total Pressures

Register No.	Test No.	Area		Ratios*		Total Pressure Ahead of Register, in. of water		Pressure Loss Ratio, $\frac{T.P.}{V.P.}$		
		Core Area sq. in.	Free Area sq. in.	Free Area to Core Area	Free Area to Duct Area	At 300 f.p.m.	At 1500 f.p.m.	At 300 f.p.m.	At 1500 f.p.m.	Average
1	2	3	4	5	6	7	8	9	10	11
R19	1J	56.3	43.5	0.773	0.604	0.024	0.500	4.31	3.57	3.94
R20	2J	58.6	51.1	0.872	0.710	0.013	0.274	2.26	1.96	2.11
R21	3J	58.6	51.65	0.882	0.718	0.013	0.274	2.26	1.96	2.11
R22	8J	58.6	52.75	0.900	0.733	0.014	0.318	2.57	2.27	2.42
R23	4J	58.6	50.1	0.855	0.696	0.018	0.335	3.16	2.39	2.78
R26	6J	58.6	52.75	0.900	0.733	0.014	0.298	2.44	2.06	2.25
R25	5J	58.6	49.8	0.850	0.692	0.017	0.344	3.06	2.46	2.76
R27	7J	56.5	46.0	0.814	0.639	0.017	0.344	3.06	2.46	2.76

*Based on least free area, measured perpendicular to oblique portion of bars.

pressure loss ratio by the average pressure increase ratio shown in Fig. 12 for the given angle of deflection.

When the bars of a register are set at an angle, instead of parallel to the axis of the duct, the resulting pressure loss consists of a loss caused by restricting the area, and a shock loss occasioned by turning the air stream. Both of these occur simultaneously in the case of the adjustable deflecting type registers. In the case of the fixed deflecting type registers, it is possible to separate these losses and to determine

TABLE 9
COMPARISON OF PRESSURE LOSS RATIOS FOR FIXED AND ADJUSTABLE DEFLECTING TYPE REGISTERS

Register No.	Observed Pressure Loss Ratio $\frac{T.P.}{V.P.}$	Based on Frontal Free Area			Based on Least Free Area*		
		Ratio of Free Area to Duct Area	Ratio of $\frac{T.P.}{V.P.}$ from Fig. 6†	Ratio of $\frac{\text{Column 2}}{\text{Column 4}}$	Ratio of Free Area to Duct Area	Ratio of $\frac{T.P.}{V.P.}$ from Fig. 6†	Ratio of $\frac{\text{Column 2}}{\text{Column 7}}$
1	2	3	4	5	6	7	8
R20	2.11	0.764	1.80	1.172	0.710	2.10	1.005
R21	2.11	0.775	1.73	1.220	0.718	2.05	1.029
R22	2.42	0.786	1.69	1.432	0.733	1.96	1.235
R23	2.775	0.732	1.96	1.416	0.696	2.18	1.273
R26	2.25	0.786	1.69	1.331	0.733	1.96	1.148
R25	2.76	0.728	2.00	1.380	0.692	2.21	1.249
R27	2.76	0.710	2.10	1.315	0.639	2.57	1.074
				Average = 1.324			Average = 1.145

*Measured perpendicular to oblique portion of bars.
†Values from curve for bar registers.

the shock loss alone by comparing the observed pressure loss ratio with that obtained from the proper curve in Fig. 6 for a register of the same type having a free area equal to the summation of the areas between the oblique bars, measured perpendicular to the bars. This area, expressed as a ratio of free area to duct area, has been designated as the "least free area," and for the different registers tested is shown in Table 9, column 6. The corresponding pressure loss ratio read from Fig. 6 is shown in column 7. The ratio of the observed pressure loss ratio to the corresponding value read from Fig. 6 is shown in column 8. The average of 1.145, obtained from column 8, represents an increase of 14.5 per cent in pressure loss resulting from the deflection of the air, as compared with the pressure loss for the same type of register with the bars set parallel to the axis of the duct. The difference 32.4 — 14.5, or 17.9 per cent, represents the increase in the pressure loss resulting from the constriction in area.

Comparing the pressure loss ratios for registers R20 and R21, shown in Table 9, column 5, it seems evident that at a given angle of deflection, it makes no material difference whether all of the air is deflected to one side, or part to one side and part to the other. Furthermore, comparing the pressure losses for registers R21 and R25, and for registers R26 and R23, it is evident that the wider spacing of the

bars gave pressure losses less than those resulting from closer spacing. This suggests that if the bars are too widely spaced, part of the air may pass through the register without being deflected. This would result in greater turbulence in the air stream after it left the register, but would not be reflected in the pressure required to force the air out of the register.

VII. Pressure Losses for Combinations of Registers and Stackheads

16. *Results of Tests.*—For the tests discussed in this section, the registers were attached to a 12-in. x 6-in. stackhead, which in turn was connected to a 3¼-in. x 12-in. stack, as shown in Fig. 1b. The dampers, or valves, furnished with the registers were placed in the open position so that their lower edges were in contact with the back wall of the stackheads. Since the total pressures were measured in the approach stack and ahead of the stackhead, the observed total pressures included the losses in both the register and the stackhead. Preliminary tests indicated that no difference in results was obtained with

Table 10
Comparison of Total Pressures for Registers Attached to Stackhead and to End of Straight Duct

Type of Register	Register No.	Register With Stackhead		Register on 12 in. x 6 in. Duct		Equivalent Lengths in Feet of Equivalent Pipe	
		Test No.*	Total Pressure at 150 c.f.m.	Test No.†	Total Pressure at 150 c.f.m.	3¼ in. x 12 in. Duct‡	6 in. x 12 in. Duct¶
1	2	3	4	5	6	7	8
6 in. x 12 in. Duct Only	....§	....	.....	....	0.0058	..	34
Stackhead Only	S1§	1N	0.031	....	.....	33	..
Perforated Grille	R1§	2N	0.047	1F	0.036	51	212
Perforated Grille	R4	7N	0.044	4F	0.033	47	194
Perforated Grille	R47	6N	0.061	29F	0.053	66	311
Bar Type	R2	4N	0.038	2F	0.017	41	100
Bar Type	R5§	9N	0.039	5F	0.013	42	76
Bar Type	R13§	10N	0.040	13F	0.013	43	76
Bar Type	R14	11N	0.040	14F	0.012	43	71
Bar Type	R15	8N	0.040	15F	0.013	43	76
Bar Type	R16§	12N	0.039	16F	0.012	42	71
Perforated Grille	R1	3N	0.053	....	.....	57	..
Bar Type	R2	5N	0.041	....	.....	44	..
Bar Type	R14	11P	0.040	....	.....	43	..

*Tests 1N, 3N, and 5N with register valve removed. All others with register valve attached.
†All tests with register valve removed.
‡100 ft. of 3¼ in. x 12 in. duct has 0.093 in. resistance at 554 f.p.m.
¶100 ft. of 6 in. x 12 in. duct has 0.017 in. resistance at 300 f.p.m.
§Represented in Fig. 15.

the stackhead in either a horizontal or a vertical position. The horizontal position proved to be more convenient, and resulted in less stratification of the air at the measuring station. Hence, this position was used in all the tests. As shown in Table 10, a representative number of registers were tested, including both perforated grille and bar types. The description and dimensions of these registers are given in Table 1.

The pressure losses for registers used in combination with stackheads are given in Table 10, column 4, and those for the same registers attached to the end of a 6-in. by 12-in. straight duct are given in Table 10, column 6. In both cases the pressure losses for an air delivery of 150 cu. ft. per min. are shown. The ratio of total pressure to velocity pressure in the duct, which was previously used as an index of pressure loss, is not significant for the purpose of comparison when the registers are tested in arrangements that are not geometrically similar. Hence, the total pressure, in inches of water, representing the pressure required to offset the losses and to deliver the air at the same velocity have been tabulated in columns 4 and 6. For an air delivery of 150 cu. ft. per min. the average velocities of approach were 300 ft. per min. and 554 ft. per min. in the 6-in. x 12-in. duct and the 3¼-in. x 12-in. stack, respectively.

The results obtained with registers R1, R5, R16, and R13 were selected as representative of the perforated grille, horizontal bar, vertical bar, and honeycomb types of registers, and a graphical representation of the data is shown in Fig. 15. In addition, the total pressures observed at Station 1 (see Fig. 1) in the duct and stackhead with the registers omitted are also shown.

With both the straight duct and the stackhead arrangements, the pressure losses for the three types of bar registers used were practically the same, and were less than those for the perforated grille registers employed. As shown in Table 10, the pressure losses for the typical bar type registers used in combination with the stackhead were approximately 27 per cent greater than the pressure losses for the stackhead alone, whereas the pressure losses for the typical perforated grille type registers were approximately 42 to 97 per cent greater. In all cases registers used in combination with the stackhead produced greater pressure losses than when they were used at the end of a straight duct. However, it may be noted that the differences in pressure losses between the perforated grille and the bar type registers were smaller when both were used with the stackhead arrangement than when they were used with the straight duct arrangement. No

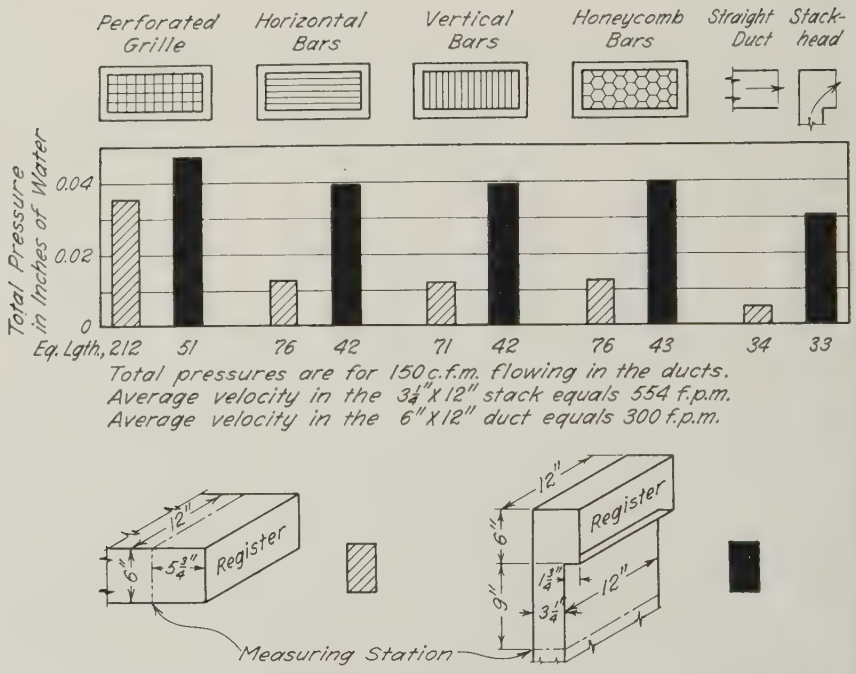


Fig. 15. Total Pressures for Registers Attached to Stackhead and to End of Straight Duct

apparent relationship could be established between the pressure losses obtained with the two different test arrangements. It may be concluded that registers should be tested in arrangements that simulate actual conditions of installation, and that results obtained with registers attached to the side of a large plenum chamber are not representative of the performance of the same registers installed at the end of a straight duct or at the face of a stackhead.

The pressure losses expressed in terms of the equivalent length of round duct, having the same equivalent diameter as the approach duct, are also shown in Table 10, columns 7 and 8. The equivalent lengths for the stackhead arrangement were considerably less than those for the straight duct arrangement, although the observed pressure losses in inches of water were actually greater. As shown in Appendix C, the statement of pressure losses in terms of equivalent lengths is entirely dependent on the size of the duct used for reference, and for this reason such a statement frequently leads to misunderstanding. In any

case the numerical values of equivalent lengths given in Table 10 are much greater than those frequently assumed in the design of duct systems.

Registers R1, R2, and R14 were also tested with the register valves removed, and the resulting pressure losses were approximately 0 to 13 per cent greater than those obtained with the valves opened so that their lower edges were in contact with the back wall of the stackhead.

VIII. Pressure Losses as Affected by Turning Vanes in Stackheads

17. *Results of Tests.*—A series of tests was conducted in which various types of turning vanes were placed in the stackhead, and the total pressures ahead of the register and stackhead combination were measured. With the exception of case (h) shown in Fig. 16, all tests were made with a vertical bar register, R14, attached to the stack-

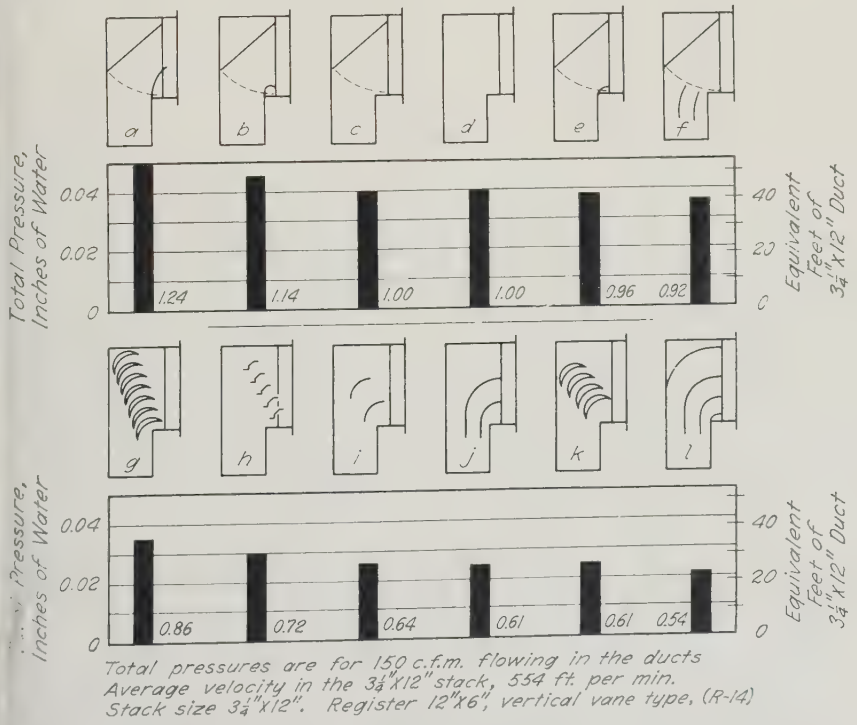


Fig. 16. Pressure Losses as Affected by Turning Vanes in Stackhead

head. The register R35 shown in case (h) was similar in type to register R14 except that it included an additional feature consisting of turning vanes built in as an integral part of the register itself.

Case (c) in Fig. 16, shows the register and stackhead combination with the valve opened and in contact with the back wall of the stackhead, conforming with conventional usage. The total pressure, or pressure loss, of 0.040 in. of water obtained with this combination at an air delivery of 150 cu. ft. per min. was considered as unity, and all other pressure losses were expressed as ratios of the observed pressure losses to this basic pressure loss. The actual values of the total pressures, arranged in descending order of magnitude, are shown in Fig. 16, by the length of the cross-hatched bars, and the ratios of these pressure losses to the basic pressure loss are shown by figures at the bottom of the bars. The total pressures are directly comparable, since all were obtained with an air delivery of 150 cu. ft. per min.

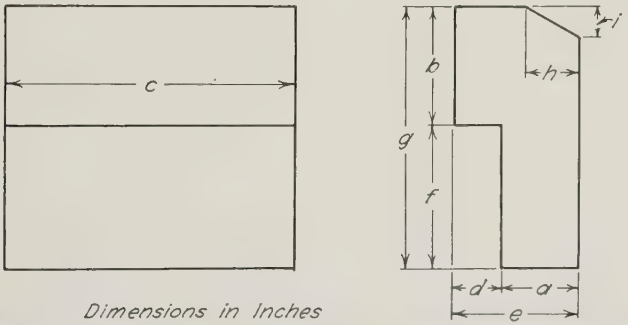
The two types of rounded throats, shown in cases (a) and (b), actually increased the pressure loss, whereas the type of inner throat shown in case (e) reduced the pressure loss by only 4 per cent. Apparently there is little to be gained by rounding the inner corner of the stackhead throat.

The use of the seven types of turning vanes shown in cases (f) to (l) resulted in reductions in pressure loss ranging from 8 to 46 per cent, indicating that a material reduction in pressure losses can be effected by the proper use of turning vanes. With the exception of case (f), the use of turning vanes in the stackhead precludes the simultaneous employment of single-vane valves. The simplest, and probably the most practical, arrangement for reducing the pressure loss proved to be that shown in case (i), which consisted of two quarter-round strips of sheet metal with the ends attached to the sides of the stackhead. These strips can be attached readily to any existing stackhead by means of sheet metal screws. Undoubtedly the use of turning vanes in the stackhead also affected the distribution of air from the register face, but comprehensive studies of such air distribution have been made by Nelson* and his associates, and hence were not considered as within the scope of this investigation. It is interesting to note that the pressure loss, for the stackhead alone, shown in Fig. 15, was greater than any of those obtained with combinations (h), (i), (j), (k), and (l), further proving that the loss in the stackhead may be greater than that through the register itself.

*Loc. cit. Note 1, see p. 1.

IX. Pressure Losses as Affected by Relative Proportions of Stacks, Stackheads, and Registers

18. *Results of Tests on Combinations of Stackheads and Registers.* —In the design of a forced warm-air heating system it is usual to limit the velocity in the stacks to approximately 500 ft. per min. Since the standard depth of stack is 3¼-in., the required air volume is then obtained by varying the width of stack, which in turn determines the width of the stackhead and register. The velocity at the register face is determined by the height of the register. In order to obtain the effect of proportions of stacks, stackheads, and registers on the pressure loss at a given velocity in the stack, a series of tests was run on the 15 different combinations presented in Fig. 17. The registers were



Dimensions in Inches

Stackhead No.	Stack Width c	Stack Depth a	Register Height b	Stackhead Dimensions d	e	f	g	h	i
1	2	3	4	5	6	7	8	9	10
S7	8	3¼	4	1⅞	5⅛	5⅞	9⅞	2¼	1¼
S8	8	3¼	5	1⅞	5⅛	5⅞	10⅞	2¼	1¼
S9	8	3¼	6	1⅞	5⅛	5⅞	11⅞	2¼	1¼
S5	10	3¼	4	1⅞	5⅛	5⅞	9⅞	2¼	1¼
S10	10	3¼	5	1⅞	5⅛	5⅞	10⅞	2¼	1¼
S6	10	3¼	6	1⅞	5⅛	5⅞	11⅞	2¼	1¼
S11	10	3¼	8	1⅞	5⅛	5⅞	13⅞	2¼	1¼
S2	12	3¼	4	1⅞	5⅛	5⅞	9⅞	2¼	1¼
S12	12	3¼	5	1⅞	5⅛	5⅞	10⅞	2¼	1¼
S1	12	3¼	6	1¾	5	3¼	9¼	—	—
S13	12	3¼	8	1⅞	5⅛	5⅞	13⅞	2¼	1¼
S14	14	3¼	4	1⅞	5⅛	5⅞	9⅞	2¼	1¼
S15	14	3¼	5	1⅞	5⅛	5⅞	10⅞	2¼	1¼
S16	14	3¼	6	1⅞	5⅛	5⅞	11⅞	2¼	1¼
S17	14	3¼	8	1⅞	5⅛	5⅞	13⅞	2¼	1¼

Fig. 17. Dimensions of Stackheads

TABLE 11

TOTAL PRESSURES* FOR COMBINATIONS OF STACKHEADS AND REGISTERS

Register Size in.	Stack Size in.	Test No.	Total Pressure Ahead of Stackhead, in. of water	Pressure Loss Ratio, $\frac{T.P.}{V.P.}$	Pressure Loss in Equivalent Length of Stack, ft.†
1	2	3	4	5	6
8 x 4	3¼ x 8	1T	0.059	3.75	65.1
8 x 5	3¼ x 8	2T	0.039	2.50	43.3
8 x 6	3¼ x 8	3T	0.029	1.84	31.9
10 x 4	3¼ x 10	4T	0.053	3.41	67.3
10 x 5	3¼ x 10	5T	0.036	2.33	46.1
10 x 6	3¼ x 10	6T	0.028	1.77	34.9
10 x 8	3¼ x 10	7T	0.023	1.47	29.1
12 x 4	3¼ x 12	22T	0.050	3.23	70.7
12 x 5	3¼ x 12	23T	0.035	2.26	49.7
12 x 6	3¼ x 12	24T	0.026	1.69	37.2
12 x 8	3¼ x 12	25T	0.020	1.26	27.7
14 x 4	3¼ x 14	26T	0.051	3.26	78.1
14 x 5	3¼ x 14	13T	0.033	2.08	50.0
14 x 6	3¼ x 14	14T	0.025	1.60	38.4
14 x 8	3¼ x 14	15T	0.021	1.32	31.7

*Pressures given for 500 ft. per min. stack velocity.

†The equivalent diameters of round pipes having the same friction loss per foot of pipe as the corresponding stack are 5.5 in., 6.1 in., 6.6 in., and 7.1 in. for 3¼ x 8, 3¼ x 10, 3¼ x 12, and 3¼ x 14 in. stacks, respectively. The corresponding friction losses per 100 ft. of stack at an air velocity of 500 ft. per min. are 0.090 in., 0.079 in., 0.071 in., and 0.065 in., as determined by F. C. Houghten (A.S.H.V.E. 1942 Guide, pp. 612-615).

of the vertical bar type equipped with horizontal multiple valves, and were all furnished by the same manufacturer.

The results of the tests are shown Table 11 and Fig. 18. The lower set of curves in Fig. 18 shows the pressure loss ratios plotted against the width of the register, the individual curves representing the pressure loss ratios for nominal register heights of 4, 5, 6, and 8 inches. For a given height of register the pressure loss ratio decreased slightly as the width of the register was increased. For example, with a register 6 in. high, the pressure loss ratio decreased from 1.85 to 1.60 as the width of the register was increased from 8-in. to 14-in. The average of 1.72 is in reasonably close agreement with the value of 1.68 shown in Fig. 18 for the 12-in. register, so that the pressure losses in Chapters VII and VIII for 12-in. x 6-in. registers attached to the proper-sized stackheads may be considered as good approximations for any widths of stacks between 8-in. and 14-in.

For a given width of register, however, the pressure loss ratio increased rapidly as the height of the register was decreased. For example, the pressure loss ratio was 1.68 for a 12-in. x 6-in. register attached to a 3¼-in. x 12-in. stack, whereas it was 3.22 for a 12-in. x 4-in.

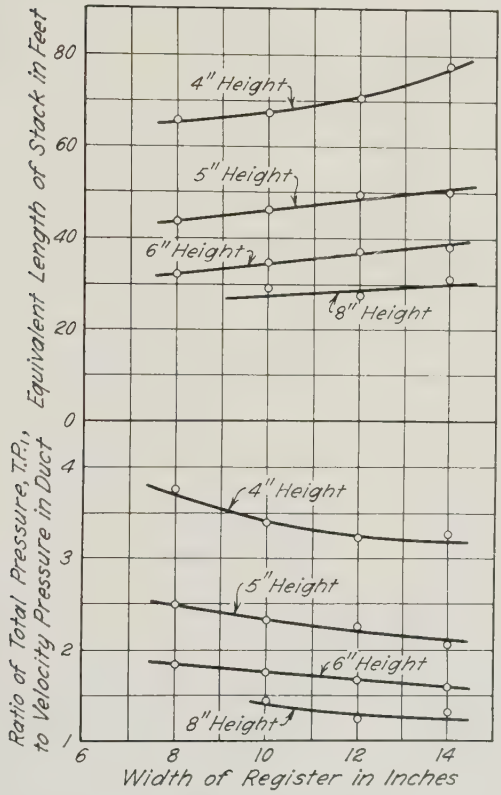


FIG. 18. TOTAL PRESSURES FOR VARIOUS COMBINATIONS OF STACKHEADS AND REGISTERS

register attached to the same sized stack. It is probable that the amount of turbulence accompanying the use of a low register was greater than it was for the higher registers. It is also possible that turning vanes placed in the stackhead would have a relatively greater effect in reducing pressure losses in the case of a low register than they would have when used in connection with higher registers.

The upper part of Fig. 18 shows the results expressed in equivalent length of stack in feet. For any given height of register the equivalent lengths increased as the width of the register was increased, whereas, in the lower set of curves, the pressure loss ratios decreased under the same conditions. The pressure loss ratio, as explained in Appendix C, is a dimensionless ratio, and, for arrangements that are geometrically similar, it is independent of the size of equipment involved. On the

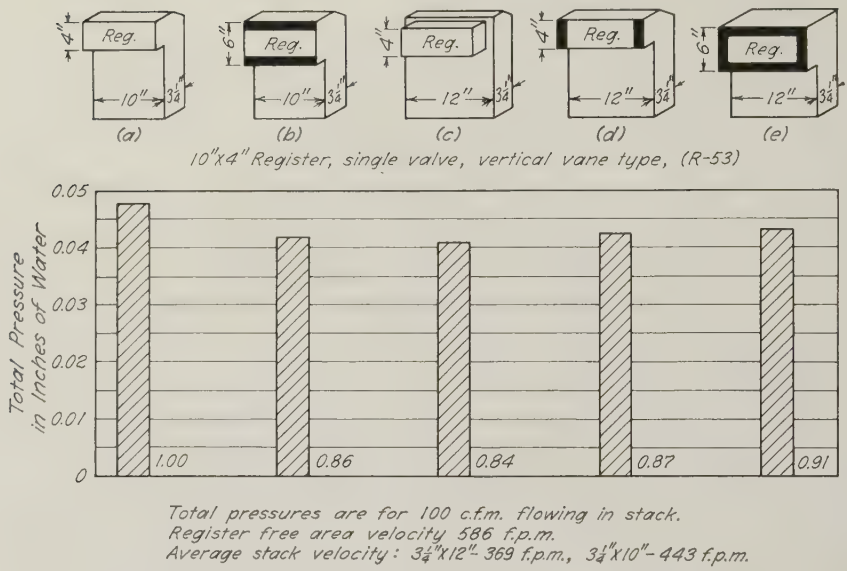


Fig. 19. Total Pressures for Registers Adapted to Oversized Stackheads

other hand, the equivalent length is a variable unit depending on the size of the duct. That is, the basic pressure loss for a given length of a large-sized duct is less than that for the same length of a smaller sized duct. Unless this is clearly understood, comparisons based on equivalent lengths are apt to prove misleading. Hence, comparisons have been based on pressure ratios, and the equivalent lengths have been shown only to indicate the magnitudes. It may be noted that the average equivalent lengths, varying from 28 to 70 ft., shown in Fig. 18, are considerably greater than the 10 to 30 ft. commonly assumed in practice.

19. *Results of Tests on Registers Adapted to Oversized Stackheads.* —In remodeling forced warm-air heating systems, it is sometimes either necessary or desirable to adapt small registers to oversized stackheads which have been previously installed. In order to determine whether such adaptations result in excessive pressure losses, a series of tests was run on the combination shown in Fig. 19, used in connection with a vertical bar type register. On the assumption that in a given new installation, design conditions require a 10-in. x 4-in. register delivering air at approximately 600 ft. per min., the proper combination of stack, stackhead, and register would be combination (a).

The pressure loss for this combination, as shown in Fig. 19, was 0.048 in. of water. This pressure loss was regarded as unity, and the ratios of pressure losses of other combinations to this unit pressure loss are shown by the figures at the bottom of the cross-hatched bars.

Other combinations of oversized stacks and stackheads that might be encountered in remodeling old installations, and the methods for adapting the 10-in. x 4-in. register to these combinations are shown as (b), (c), (d), and (e) in Fig. 19. It may be observed that the pressure losses were in all cases smaller than that given by combination (a), the ratios ranging from 0.84 to 0.91. Hence there seems to be no objection to adapting a register to an oversized stack and stackhead, and estimating the pressure losses from the proper combination that would normally have been used under the same circumstances in a new installation.

X. Conclusions

20. *General Conclusions.*—The following conclusions may be drawn as applying to the apparatus used and the conditions under which the tests were conducted:

(1) Registers should be tested in arrangements that simulate actual conditions of installation. Results obtained with registers attached to the side of a large plenum chamber are not representative of the performance of the same registers installed at the end of a straight duct or at the face of a stackhead.

(2) The static pressure existing in the duct ahead of a register is not a measure of the actual resistance of a register. It is not possible to evaluate separately the actual resistance of a register. However, the total pressure existing in the duct ahead of the register, representing the combined resistance and final velocity pressure, is a reliable index of performance, and can be used in connection with the other resistances in a duct system to evaluate the total head on a fan.

(3) The pressure loss through a register may be comparable with the total amount of pressure available for forcing the air through a warm-air duct system, and the necessity for taking into consideration the pressure losses of the individual registers used cannot be too strongly emphasized.

(4) In general, the pressure losses for perforated grille type registers are greater than those for bar type registers.

(5) Wall and ceiling surfaces adjacent to a register have no effect on the pressure loss through the register.

(6) The pressure loss for a register is greatly influenced by the size of the border. A slight increase in the size of the border may result in a large increase in the pressure loss.

(7) Setting the deflecting vanes in a register to deflect the air stream more than about 30 degrees results in excessive pressure losses.

(8) The pressure loss in the stackhead itself constitutes a large portion of the total loss for a stackhead and register combination.

(9) No material reduction in pressure losses can be effected by rounding the throat of a stackhead.

(10) A material reduction in pressure losses can be effected by the proper use of turning vanes in the stackhead.

(11) At a given velocity in the stack, with a given height of register installed in a stackhead, the pressure loss decreases only slightly as the width of the register is increased. On the other hand, with a given width of register, the pressure loss increases rapidly as the height is decreased.

Appendix A

Calibration of Air-Measuring Station

In order to calibrate the measuring station shown in Fig. 1, a 12-point traverse was made in the 6-in. round duct. This traverse consisted of velocity pressures read at six points on a vertical diameter and similar velocity pressures read at six points on a horizontal diameter. The duct was divided into three imaginary concentric zones and readings of velocity pressure were made at the intersections of the vertical and horizontal diameters with circles drawn through the center of the area of each concentric zone. Traverses were made at 13 different velocities, and, during the traverses at each velocity, the velocity pressure at the measuring station was maintained constant. The calibration curve giving the relation between the velocity pressure in the center and the actual weight of air flowing, as determined by the traverse, is shown in Fig. 20. The maximum deviation from the average curve of any point representing an individual traverse did not exceed approximately 0.9 per cent. Tests made under conditions of minimum fan speed combined with maximum opening of the inlet cone, and also of maximum fan speed combined with minimum opening of the inlet cone proved that the method of control had no effect on the character of air flow at the measuring station and therefore on the calibration of the station.

The following equations were used in the calculations for the air weights:

$$d_a = \frac{1.327\,(b - 0.378\,p_w)}{460 + t} \tag{1}$$

$$v_a = 18.27\sqrt{\frac{h}{d_a}} \tag{2}$$

$$Q_a = 60Av_a \tag{3}$$

$$W_a = 60Q_a d_a \tag{4}$$

$$W_s = W_a\sqrt{\frac{d_s}{d_a}} \tag{5}$$

in which d_a = density of air at pressure, temperature, and moisture content existing during test, in lb. per cu. ft.

b = barometric pressure corrected for temperature, in inches of mercury

p_w = partial pressure of water vapor, in inches of mercury. This is equal to the product of the relative humidity and the saturation pressure of water vapor, p_s, at temperature t

t = dry-bulb temperature of air, in deg. F.

v_a = velocity of air under actual conditions, in ft. per sec.

$\sqrt{h}$ = average of the square roots of the velocity heads, as determined by the traverse

Q_a = quantity of air under actual conditions, in cu. ft. per min.

A = area of duct, in sq. ft. At the measuring station, the internal area was 0.194 sq. ft.

W_a = weight of air under actual conditions, in lb. per hr.

W_s = weight of air corrected to standard density, in lb. per hr.

d_s = density of standard air, or air having a density of 0.075 lb. per cu. ft.

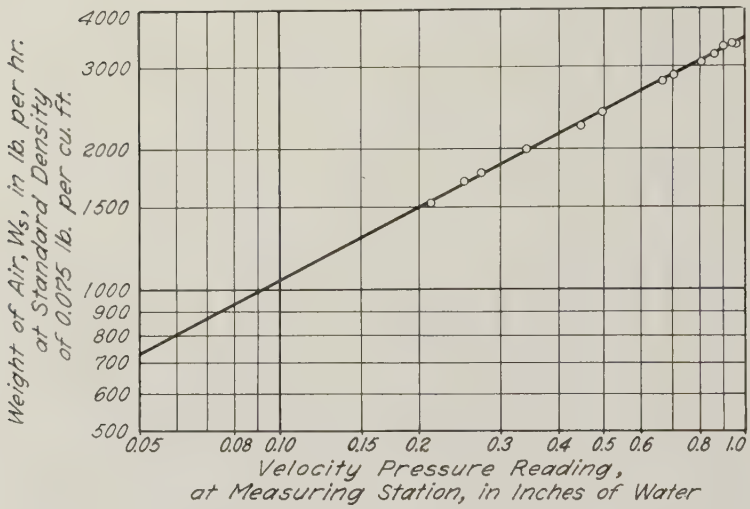


FIG. 20. CALIBRATION CURVE FOR MEASURING STATION

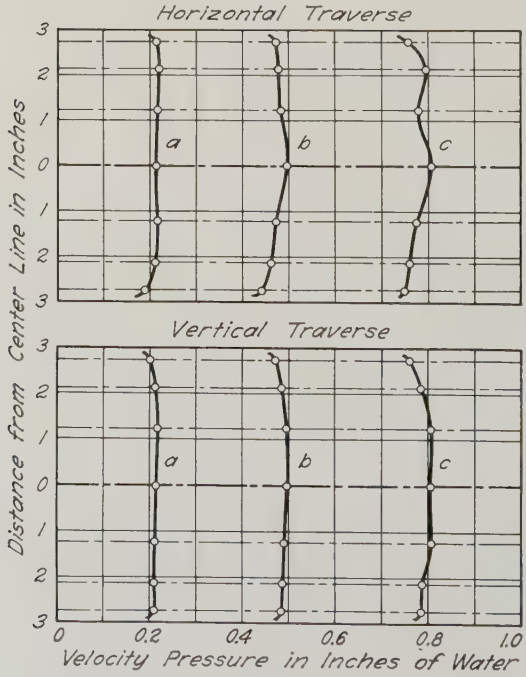


FIG. 21. TYPICAL VELOCITY PRESSURE PROFILES AT AIR-MEASURING STATION

After the calibration curve was established, it was only necessary to make readings with the pitot tube located at the center of the measuring station, and the weight of standard air could then be obtained from the curve. The actual weight was obtained by correcting the standard weight to actual conditions through the use of the equation

$$W_a = W_s \sqrt{\frac{d_a}{d_s}} . \tag{6}$$

Typical velocity pressure profiles obtained at the air-measuring station are shown in Fig. 21. These profiles were comparatively flat, indicating that the velocity pressure was very nearly constant over the whole area of the measuring section.

Appendix B

Total Pressure Ahead of Register as a Measure of Pressure Loss

1. *Total Head on Fan.*—A fan operating in a duct system creates the velocity at the entrance, overcomes losses on the suction and discharge sides, and creates any additional velocity on the discharge side. The total head on a fan, as shown in Fig. 22, can be expressed by the following equation:

$$h_t = R_e + R_i + R_d + R_r + VP \tag{1}$$

in which h_t = total head on fan, in inches of water

R = pressure loss, or resistance to air flow, in inches of water. The subscripts e, i, d, and r refer respectively to entry, inlet duct, discharge duct, and register

VP = velocity pressure at register, in inches of water.

In the study of pressure losses in registers, the terms representing the resistance of the register, R_r, and the velocity pressure at the register face, VP, were of immediate interest.

As indicated in Chapter I, Section 1, resistances, or pressure losses, must be determined from differences in total pressure. That is,

$$R_r = T.P._1 - T.P._2 \tag{2}$$

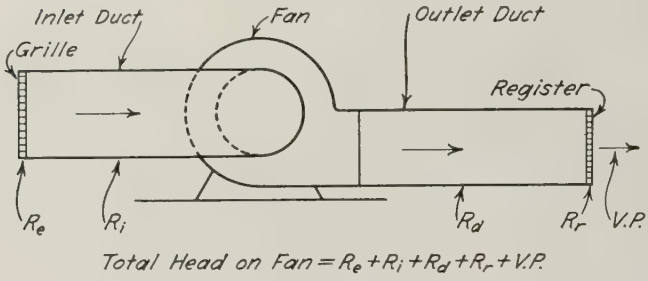


FIG. 22. TOTAL HEAD ON A FAN

in which $T.P._1$ = total pressure on upstream side of register, in inches of water

$T.P._2$ = total pressure at register face on downstream side, in inches of water.

In Sections 2 and 3 of this Appendix, a discussion is presented of the methods used in obtaining $T.P._1$ and the difficulties encountered in the evaluation of $T.P._2$.

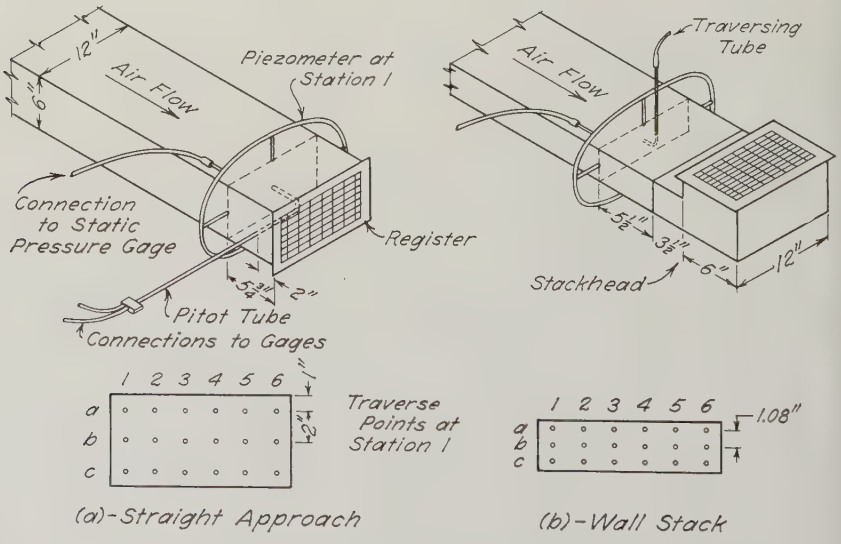


FIG. 23. ARRANGEMENT FOR MEASUREMENT OF PRESSURES ON UPSTREAM SIDE OF REGISTER AT STATION 1

TABLE 12
TOTAL PRESSURE, $T.P._1$, OBTAINED BY TRAVERSE AND BY SEPARATE DETERMINATIONS OF $V.P._1$ AND $S.P._1$

Item No.	Test Arrangement	6 in. x 12 in. Duct*				3¼ in. x 12 in. Stack†
	Test No.....	1B	3B	4B	5B	7M
1	$V.P._1$ corresponding to mean velocity	0.134	0.087	0.133	0.133	0.118
2	$V.P._1$ by traverse	0.138	0.088	0.135	0.127	0.121
3	Deviation, in per cent	−2.9	−1.1	−1.5	+4.7	−2.5
4	$S.P._1$ by piezometer	0.286	0.233	0.358	0.491	0.220
5	$S.P._1$ by traverse	0.300	0.237	0.365	0.495	0.227
6	Deviation, in per cent	−4.6	−1.7	−1.9	−0.8	−3.1
7	$T.P._1$ from items 1 and 4	0.420	0.320	0.491	0.624	0.338
8	$T.P._1$ by traverse	0.438	0.325	0.500	0.622	0.348
9	Deviation, in per cent	−4.1	−1.5	−1.8	+0.3	−2.9

*Pitot tube diameter ⅜ in.
†Dynamic tube and static tubes were ⅛ in. in diameter.

2. *Total Pressure Ahead of Register, $T.P._1$.*—In determining the value of $T.P._1$, shown in Equation (2), two methods of procedure were open. The obvious course was to make a traverse with a dynamic, or total pressure, tube at Station 1, as shown in Fig. 23. However, the time required for making even a single traverse, during which the air volume had to be maintained constant, was so great that this method was practically prohibitive for an extensive program of tests. Since

$$T.P._1 = V.P._1 + S.P._1 \tag{3}$$

in which $V.P._1$ and $S.P._1$ refer respectively to the velocity pressure and static pressure at Station 1, a simplified procedure was used in which $V.P._1$ and $S.P._1$ were separately determined.

The average velocity pressure at Station 1, Fig. 23, as obtained directly from an 18-point traverse, was found to be in close agreement with the velocity pressure corresponding to the mean velocity, computed from the weight of air measured at the main measuring station. As shown by Table 12, item 3, the deviation of the average velocity pressure determined by traverse from that computed from the weight of air flowing was about 2½ per cent for four separate tests. Similar tests made on the stackhead-register arrangement, presented in Fig. 1b, also showed an average difference between the two values of about 2½ per cent. Since the mean velocity head, obtained by traversing the

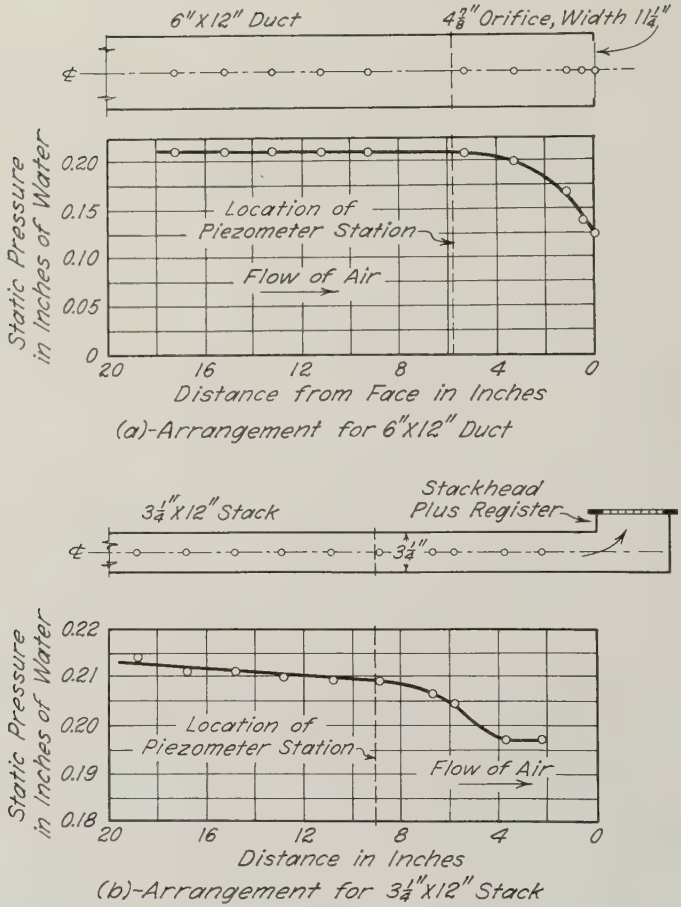


Fig. 24. Static Pressure Gradient in Duct and Location of Piezometer Connection

duct with a pitot tube, agreed closely with the head corresponding to the mean velocity, computed from the weight of air flowing, the values of $V.P._1$ obtained by the latter method were used in subsequent tests on registers.

As shown in Fig. 24a, preliminary surveys of the static pressure gradient in the duct on the upstream side of the register indicated that the static pressures changed very abruptly within a few inches of the register. Static pressures measured within this narrow critical zone would not be representative of the static pressure required to force the air out of the register. Hence, in the case of the 6-in. x 12-in.

straight duct, at the end of which the register was attached, the piezometer connection was made 5¾ inches from the register in order to be just outside of the critical zone. In the case of the 3¼-in. x 12-in. stack, to which the stackhead and register were attached, the piezometer connection was made 9 inches from the bottom of the stackhead opening, as shown in Fig. 24b.

The static pressure at Station 1, Fig. 23, as obtained from an 18-point traverse using the static connection of the pitot tube only, was found to be in close agreement with the average static pressure obtained by means of the piezometer. As shown by Table 12, item 6, the average deviation in static pressures obtained by the two methods was 2.3 per cent for four separate tests. Similar tests made on the stackhead arrangement showed a deviation of 3 per cent. Since the static pressure directly determined from a traverse agreed closely with the static pressure obtained by means of the piezometer, the values of $S.P._1$ obtained by the latter method were used in subsequent tests on registers.

As shown by Table 12, item 9, the value of $T.P._1$ obtained by an 18-point traverse, and that determined from the sum of the calculated $V.P._1$ and the $S.P._1$ obtained from the piezometer, were in acceptable agreement. The average deviations were 1.9 per cent and 2.9 per cent, respectively, for the 6-in. x 12-in. duct and the 3¼-in. x 12-in. stack. Therefore, in obtaining the value of $T.P._1$, shown in Equation (2), the mean value of $V.P._1$ was determined from the weight of air measured at the measuring station, the value of $S.P._1$ was obtained by means of the piezometer, and the sum of $V.P._1$ and $S.P._1$ was used as the total pressure, $T.P._1$, thus eliminating the necessity for making a complete traverse during each test.

3. *Total Pressure at Face of Register, $T.P._2$.*—In determining the total pressure at the register face on the downstream side, $T.P._2$ in Equation (2), two courses again seemed to be open. The velocity head corresponding to the mean velocity could be calculated from the weight of air flowing and the free area of the register; and, if the static pressure at the register face were assumed to be zero, the total pressure would then be equal to the calculated velocity pressure. The second course open was actually to traverse the register face with a dynamic tube.

Studies of the static pressure gradient in the duct, through the register, and in the air stream leaving the register were made by means of a small static tube, as shown in Figs. 25a and 25b. The results ob-

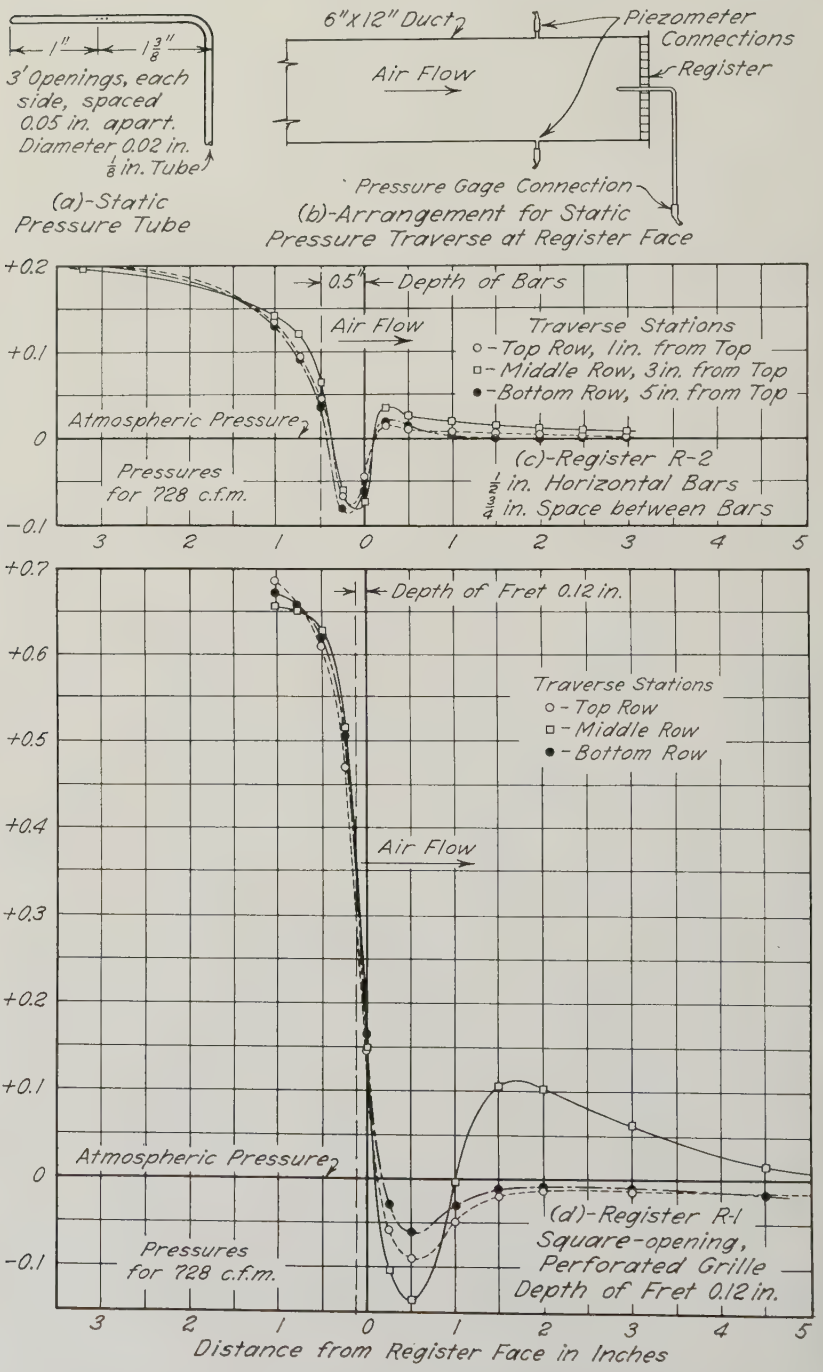


FIG. 25. TYPICAL VARIATIONS IN STATIC PRESSURE ON UPSTREAM AND DOWNSTREAM SIDES OF REGISTER

tained for a characteristic bar-type register are shown in Fig. 25c. It is obvious that the static pressure was not zero at either the inside or outside surface of the register face. Furthermore, since the static pressure was extremely variable over a distance extending from one inch inside to one inch outside of the register face, it is apparent that the velocity of the air was also varying over this distance. Hence, while the static pressure did become zero at some indeterminate point within the register face, there was no assurance that the velocity at this point corresponded to the calculated free area velocity. Similar characteristics were exhibited by the pressure gradient in the case of the perforated grille register, as shown in Fig. 25d, except that the minimum static pressure occurred at a distance of about ½ inch on the downstream side of the register face, instead of within the bars as shown in Fig. 25c. It was, therefore, apparent that the calculated free area velocity could not be used in connection with an assumed static pressure of zero in order to obtain the total pressure.

In addition, it is also evident that, since both the static and velocity pressures were varying over an indeterminate distance both inside and outside of the register face, there was no section, definitely located with respect to the register, in which the velocity changes brought about by the register could be considered as completed. Hence there was no section over which a total pressure traverse could be made with the assurance that the total pressure so determined could be considered as representative of the real total pressure on the downstream side of the register, or $T.P._2$ as designated in Equation (2).

Since neither of the two methods discussed proved feasible for measuring $T.P._2$, it became evident that it was not possible to evaluate separately R_r, the true resistance of the register. However, the observed total pressure, $T.P._1$, was a measure of the combined resistance of the register, R_r, and final velocity pressure, $V.P.$ Since this was true, the last two terms in Equation (1) could be combined and expressed as

$$T.P._1 = R_r + V.P. \tag{4}$$

Equation (1) could then be rewritten

$$h_t = R_e + R_i + R_d + T.P._1 \tag{5}$$

and $T.P._1$, characteristic of the different types of registers, could be determined from the tests and used in connection with Equation (5). For purposes of discussion and comparison, the observed total pressure, $T.P._1$, has been designated as the *pressure loss*.

Appendix C

Methods of Expressing Pressure Loss

1. *Pressure Loss in Terms of Inches of Water.*—A typical curve of pressure losses for a register is shown as curve (1) in Fig. 26a. The pressure loss, in inches of water, was plotted against velocity in the approach duct, in feet per minute, both to a logarithmic scale. The curves for the registers tested consisted of straight lines having slopes ranging from about 1.85 to 1.98. Hence the pressure losses were approximately a function of the square of the velocity. The method of expressing pressure losses in inches of water as shown in Fig. 26a, has a certain merit in that the losses are stated in fundamental units of measurement and can, therefore, be used directly in the design of a duct system. This method, however, has the disadvantage that a separate curve, or an equivalent table, is required for each register tested, thus making the presentation of results rather cumbersome. Hence, simpler methods by means of which the pressure loss for each register can be expressed as a single numerical index are desirable. Two such methods are commonly used, consisting of (1) expressing the pressure loss in terms of the velocity pressure in the approach duct, and (2) expressing the pressure loss in terms of the equivalent feet of approach duct.

2. *Pressure Loss in Terms of Velocity Pressure in Approach Duct.*—Curve (2) in Fig. 26a shows the velocity pressure corresponding to the mean air velocity in the duct, and is a graphical representation of the equation

$$V = 1096.5 \sqrt{\frac{h_v}{d}} \qquad (1)$$

in which V = velocity, in feet per minute

h_v = velocity head, or pressure, in inches of water

d = density of air, in lb. per cubic foot.

For air at a standard density of 0.075 lb. per cu. ft., Equation (1) simplifies to the following form

$$V = 4005 \sqrt{h_v}. \qquad (2)$$

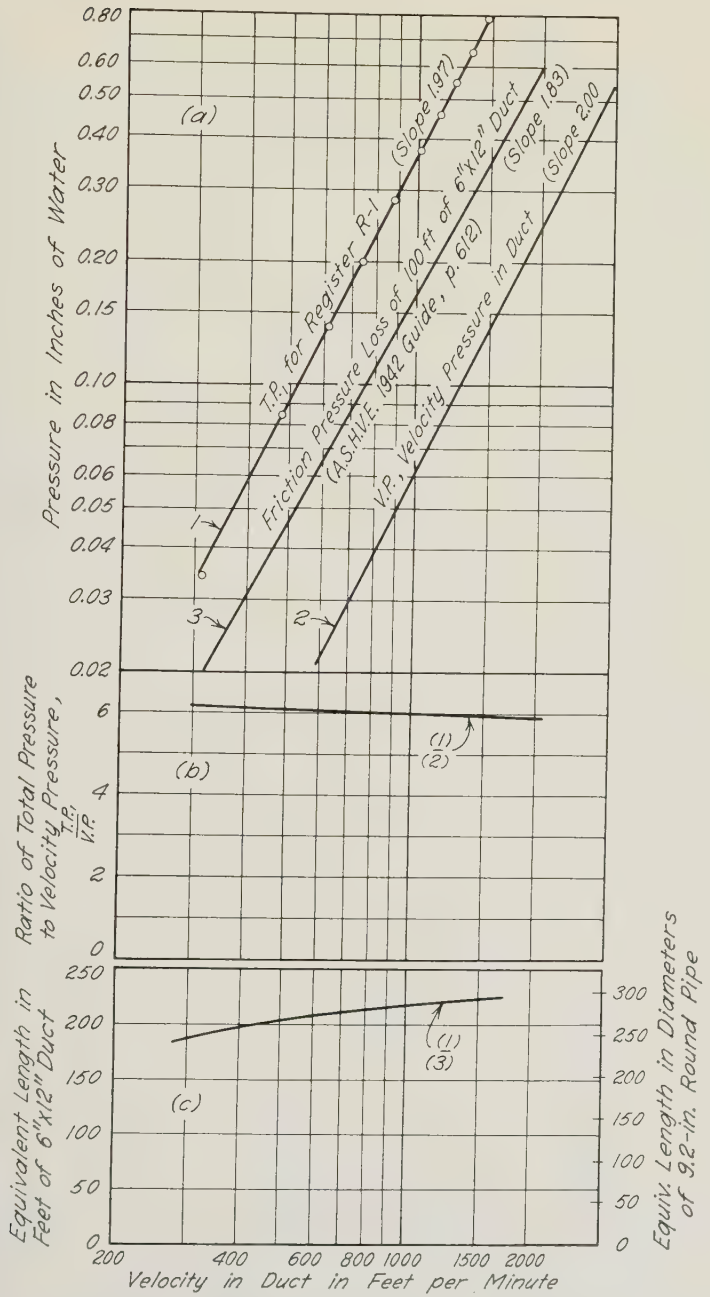


FIG. 26. METHODS OF EXPRESSING PRESSURE LOSS

It may be observed that the velocity pressure is independent of duct size or construction, and is a function only of air velocity, so that if the latter is known, the pressure can be calculated readily.

A curve representing the ratios obtained by dividing values from curve (1) by the corresponding values from curve (2) at the same velocities, is shown in Fig. 26b. The pressure loss ratio over a wide range of velocities was almost constant, so that for all practical purposes an average value selected midway between the velocities of 300 to 1500 ft. per min. serves as a convenient index of the pressure loss over a wide range of velocity. Since this ratio is dimensionless, it has the further advantage that it is applicable to different sizes of the same type of registers and can, therefore, be used as a general statement of the performance of a series of similar registers when tested in connection with similar ducts. For this reason it has been largely used in this bulletin, but, for purposes of comparison, its use is limited to test arrangements in which the approach ducts are geometrically similar.

3. *Pressure Loss in Terms of Equivalent Feet of Approach Duct.*— A third method of representing pressure losses is that shown in Fig. 26c, which was derived by dividing the values from curve (1) by those from curve (3) in Fig. 26a. Curve (3) shows the relation between air velocity in the duct and the friction pressure loss of 100 feet of commercial duct, 6-in. x 12-in. in size.* Hence the curve shown in Fig. 26c expresses the pressure loss of the register in terms of the number of feet of straight duct required to give the same pressure loss as that given by the register. This is known as the "equivalent feet of duct," and can also be expressed in terms of the number of diameters of equivalent round pipe, as shown in the right hand ordinate of Fig. 26c.

This third method of expressing pressure loss is frequently used in practice in estimating the equivalent total length of a duct system. It has the disadvantage that, even with geometrically similar ducts, the pressure loss is dependent on both the size and construction, and a unit based on using such a duct as a reference is variable rather than constant. That is, at the same air velocity the pressure loss of small ducts is materially greater than that for large ducts, so that the numerical values shown in the ordinate of Fig. 26c apply only to the specific size and type of duct used. With this limitation in view, this unit has been occasionally used in expressing results reported in this bulletin.

*American Society of Heating and Ventilating Engineer's Guide, 1942, p. 612.

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